BUILDING CONSTRUCTION

W. B. McKAY

VOLUME TWO

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BUILDING CONSTRUCTION

By the Same Author

BUILDING CONSTRUCTION

Volumes One and Three

BUILDING CONSTRUCTION

VOLUME TWO

BY

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PREFACE

VOLUMES II and III are devoted to those parts of Building Construction which are regarded as suitable for a second-year course. Brickwork, drainage, masonry and mild steel roof trusses are dealt with in Vol. II (this volume), carpentry, joinery and roof coverings in Vol. III.

One of the aims of the author has been to treat the subject sufficiently comprehensively in order to meet, as far as possible, the individual requirements of both students and lecturers concerned with the examinations of the Royal Institute of British Architects and allied professional bodies, and for National Certificates and Diplomas in Building. A wide syllabus has therefore been adopted to meet a variety of needs. It is not intended that the whole syllabus should be covered by one class in one session, but rather that most classes should be able to select those parts of the syllabus that apply specially to them. The syllabus adopted has been divided into seven parts, and these appear as headings of the respective chapters of both volumes.

Materials have been treated at some length. Much of the description in smaller type is intended for the more advanced students and for reference purposes.

Because of the relatively large size of many of the drawings it has been possible to include associated details for convenient reference. Thus, for example, Fig. 47 incorporates complete details of the small steel roof truss. Again, the several openings showing the stone dressings in Fig. 38 are detailed in Fig. 39 on the opposite page. It is hoped that the arrangement of the details in the full-page drawings especially will be of assistance to students preparing homework sheets and testimonies of study. A Homework Programme appears on p. 129. This is suggestive only, to be departed from according to the requirements and capacity of the students. Its purpose is not the production of sheets identical in detail and composition.

The author wishes to express his appreciation to several colleagues for their valuable criticisms and suggestions during the preparation of this volume, and particularly to Mr V. C. Barnes, A.R.I.B.A., Mr D. A. G. Reid, B.Sc., A.M.I.C.E., and Mr A. V. Wilson, M.Sc.Tech., M.I.Struct.E. His thanks are also due to the Controller, H.M. Stationery Office, for kindly allowing the inclusion of extracts from several British Standard Specifications, many more of which have been consulted. He is also indebted to the Director of the Building Research Station for permission to quote from the Reports of the Building Research Board, 1933 and 1936. Acknowledgment has been made in the text to several firms who have readily supplied information on building materials and processes of manufacture.

W. B. McK.

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CHAPTER ONE

BRICKWORK

Syllabus.—Extended description of the manufacture and characteristics of bricks, cements and limes; lime and cement mortars; concrete. Squint quoins and junctions, and rebated and splayed jambs in English and Flemish bonds; piers; cavity walls; circular work; reinforced brickwork; raking bonds; garden, cross, Dutch, brick-on-edge and facing bonds; recessed, elliptical, pointed and rere arches. Damp proofing of basements; dry areas. Stepped foundations. Concrete floor construction. Decorated brickwork. Fireplaces, flues, chimney breasts and stacks; bye-laws. Setting out.

MATERIALS[1]

A BRIEF description of certain building materials is given in Vol. I. These will now be considered in greater detail.

BRICKS

Bricks are chiefly made from clay and shale, and are moulded either by hand or machinery. The principal elements of clay suitable for brick-making are alumina and silica. Alumina renders the clay plastic, and thus facilitates the moulding process; if incorrectly proportioned it will cause the bricks to crack, twist and shrink excessively when being burnt. The silica may be combined with the alumina or it may be free in the form of sand; if combined, it has a tendency to produce shrinking and warping, but if free it counteracts this tendency and assists in the production of hard, durable and uniformly shaped bricks; brittle bricks will result if the sand content is excessive.

Brick clays may also contain varying proportions of limestone, iron, magnesia, salts such as magnesium sulphate, sodium sulphate, potassium sulphate and calcium sulphate, in addition to organic matter and water.

Limestone or chalk has the effect of reducing shrinkage and acting as a flux during the burning process, causing melting and binding of the mass. It influences the colour of bricks. The limestone should be present only in a fine state of division (the size of the particles not exceeding " pin-heads "), otherwise the pieces of quicklime (see p. 20) will slake and expand if the bricks absorb moisture. Such expansion will crack or shatter the bricks. Fine grinding of the clay will prevent damage from this cause. An excess of chalk will produce mis-shaped bricks when being burnt.

Iron oxides and magnesia also influence the colour of bricks (see p. 12). Salts may cause efflorescence (see p. 13). Organic matter, if in excessive quantity, may contain compounds which discolour plaster. Certain salts, particularly magnesium, may cause the bricks to decay.

Suitable clays for brick-making include " reds," " marls," " gaults," " loams," " Knotts " and " plastics."

RED CLAYS are found in many parts of the country and are extensively used for producing high-class bricks. As is implied, the colour of these bricks is red in various shades, depending upon the proportion of iron oxide present. Red bricks which are particularly noteworthy are those from Berkshire, Durham, Hampshire, Lancashire, Leicester, Yorkshire and the vicinity of Peterborough.

MARLY OR LIMY OR CALCAREOUS CLAYS have a large chalk or limestone content and are commonly used. Sand is sometimes added to such clays to prevent the bricks fusing during the burning process. Marly clays are converted into *malm* by the addition of chalk in correct proportion. In producing malm, the clay and chalk are separately reduced to a slurry or slip in wash mills. The clay *wash mill* is a cylindrical tank in which harrows of vertical metal teeth, attached to horizontal arms, are rotated to churn up the contents. The mill is stopped at intervals to allow stones and larger grains of sand to settle to the bottom, leaving the liquid with the clay in suspension. The chalk is washed in a similar mill, but a spiked roller instead of the harrows is used to break up the lumps to a fine state of division. The washed clay and chalk are now mixed together in exact proportions and passed through a screen to a *wash-bank* or shallow settling tank where the surplus water is run off, leaving the malm. Marl and malm bricks are almost white in colour. The approximate analysis of marl includes 33 per cent. silica, 10 per cent. alumina, 30 per cent. chalk and 5 per cent. oxide of iron. Well-known white bricks are obtainable from Cambridgeshire, Lincolnshire and Suffolk.

GAULT CLAYS are heavy, tough and of a bluish colour, but with sufficient chalk content to render the bricks of a pale yellow or white colour when burnt. Bricks, called *gaults*, made from such clays are often perforated (see p. 18) or have a large frog to reduce the weight; they are very satisfactory for general building purposes.

LOAMY OR MILD CLAYS have a high silica content, and the addition of a flux, such as chalk, is often necessary. Shrinkage of these clays during burning is relatively small, and they produce bricks of excellent quality. Compared with marls, a loamy clay may consist of approximately 65 per cent. silica, 27 per cent. alumina, 0·5 per cent. chalk and 1 per cent. iron.

KNOTTS CLAY is found in deep seams in the neighbourhood of Peterborough, and as it contains a relatively large proportion of finely distributed combustible matter, an economy in fuel for burning results. Fletton bricks (see p. 10) are produced from

[1] Consideration of much of this description of materials can be deferred until the Third Year of the Course. It is given here in somewhat extended detail for the purpose of reference.

this clay in enormous quantities. The approximate composition is 50 per cent. silica, 15 per cent. alumina, 10 per cent. lime, 7 per cent. iron, 5 per cent. carbonaceous matter, together with water and traces of magnesia, potash and soda.

PLASTIC OR STRONG CLAYS are composed chiefly of silica and alumina in combination, and chalk of a creamy consistency must be added to prevent distortion and excessive shrinkage in drying and burning. *London clay*, from which the well-known London stock bricks are made (see p. 11), is of this class.

CLAY SHALES, quarried in Durham, Lancashire and Yorkshire particularly, produce excellent bricks. Shale is a hard, laminated rock which is reduced to a plastic mass suitable for brick-making by weathering and the addition of water (see next column). It is found, often in the same quarry, with a varying content of oxides of iron, etc., and the careful blending of these shales produces bricks, used for faced work, of different shades. A typical shale may contain roughly 60 per cent. silica, 25 per cent. alumina, 0·6 per cent. chalk, 7 per cent. oxides of iron, 2 per cent. magnesia and traces of alkalis (potash and soda), organic matter and water.

FIRECLAY is quarried in Lancashire, Durham, Northumberland, Yorkshire, Staffordshire and other parts of the country. It contains a large proportion of silica (varying from 50 to 70 per cent.) and little, if any, lime and iron. Bricks made from such clay are highly resistant to high temperature and are therefore suitable for the lining of furnaces and fireplaces.

MANUFACTURE OF BRICKS

The various methods of production are determined very largely by the nature of the clay or shale, and may be divided into the (*a*) semi-dry or semi-plastic process, (*b*) stiff-plastic process and the (*c*) plastic process.

(a) *Semi-dry or Semi-plastic Process.*—The clay or shale is comparatively dry. It is ground to a fine powder by heavy rollers, passed through a screen, mixed to a uniform consistency, pressed and re-pressed in moulds by very powerful machinery (see p. 3) and burnt. Sometimes the screened material is damped by sprayed water. Because of the dryness of the material the bricks are taken direct from the moulding machine to the kiln, the usual intermediate drying stage being omitted. The process is relatively cheap. This process is adopted for the production of Flettons, owing to the suitability of the Knotts clay.

(b) *Stiff-plastic Process.*—This process, which is being adopted to an increasing extent, is similar to the above, except that the water content of the material is increased and therefore less powerful machinery is required to mould the bricks (see p. 3). A separate drying plant is not always necessary. The process is usually applied to hard, dry clays, such as marls, and certain shales ; it may also be applied to wetter clays, provided they have been partially dried before being crushed.

(c) *Plastic Process.*—The clay suitable for this process contains a large proportion of moisture, and is used for making wire-cut and hand-made bricks (see pp. 3 and 4). The bricks must be carefully dried before being burnt.

The various processes of (1) preparation of the clay or shale, (2) moulding, (3) drying and (4) burning are briefly described in Vol. I.

1. PREPARATION.—The top soil, or *overburden* or *callow*, is first removed. Clay is dug either by hand or by mechanical excavators such as a *steam-navvy*, which consists of a jib having a bucket with steel claws attached. The bucket is pressed against the base of the quarry face, and as it ascends the claws remove the clay which passes into the bucket ; the jib is swung round until the bucket is over a wagon which receives the clay discharged from it. Shale is usually loosened by blasting and then filled into wagons either by hand or by means of the steam navvy.

Weathering.—In the absence of crushing machinery, certain clays are subjected in winter to exposure to the weather. This is usual in small works where moulding and subsequent operations are only carried out during the spring and summer months and the clay is dug in the autumn. The excavated clay is spread over the ground for a slight depth (not more than 2-ft.) to allow the action of the frost to break down the clay into minute particles. Stones, roots, etc., are removed, whilst at least once during the winter the clay is turned over to increase the exposure and improve its workability.

There are several methods of conveying the clay or shale from the quarry or pit. One form consists of an " endless wire rope " to which the bogies or wagons are attached ; the moving rope drags the full wagons (which run on rails) up the incline to the mill as the empty wagons descend and return to the pit. Alternatively a motor tractor may be used to haul the wagons.

Cleaning.—Some clays require to be " cleaned." Stones, coarse vegetable matter, etc., may be removed either by hand picking, or the clay may be passed through a wash mill.

Blending.—Clay or shale used for making common bricks is usually taken as quarried direct to the crushing machinery. That for the more expensive bricks, especially multi-coloured facings (see p. 13), often requires the material from different strata to be mixed together as required. This important operation, known as blending, includes the removal of any undesirable material. The selection of the various clays or shales is made at the quarry-face and the blending is performed by one or more mechanical mixers, in conjunction with the grinding or crushing machine.

Reduction.—The machinery for reducing the clay or shale to a fine condition depends a good deal upon the character of the material. Thus, an *edge-running mill* is suitable for hard, dry clays which have been previously crushed by a *stone breaker*, whereas *crushing rolls* are effectively employed for plastic clays.

One form of stone breaker or disintegrator consists of a rapidly rotating shaft from which hammers are hung to break up the material to a coarse powder.

There are three types of *edge-runners* or *grinding mills*, *i.e.* (1) *dry* or *revolving pans*, (2) *wet pans* and (3) *pan mills*. A dry pan consists of two heavy metal rollers which rotate in a revolving pan having a perforated base ; the latter may be 10-ft. in diameter and the size of the perforations varies from $\frac{1}{16}$ to $\frac{1}{2}$-in. ; water is added to the clay or shale as required during the grinding operation, and the crushed material passes through the base to a pit or is conveyed by a belt to the moulding machine. A wet pan or *chaser mill* has two rotating rollers or runners which revolve in a fixed pan, the base of which is in the form of a grating having $\frac{1}{4}$ to $\frac{3}{4}$-in. slots through which the crushed material is forced ; the material is softened by water which is sprayed over it. A pan mill or *tempering mill* consists of a pair of runners and a solid revolving pan which receives a measured charge of clay and a definite amount of water ; grinding proceeds for about twenty minutes before the material is removed. A *pug mill* may be used in lieu of a pan mill, and consists of a vertical metal cylinder in which curved

knives attached to a rotating shaft churn up the clay and force it downwards through the outlet at the base.

Crushing rolls are used for reducing clays of high plasticity. The rolls, driven at a speed which varies from 50 to 160 or more revolutions per minute, are in pairs, and are strong metal cylinders placed horizontally, side by side, with a space between ; they are from 1½ to 3-ft. diameter and 2 to 3-ft. long. The clay is fed between the rollers from a hopper fixed above them. The surface of the rolls may be smooth or they may be either toothed, spiked, corrugated, etc., when they are called *kibblers*. The rolls may consist only of a single pair, or there may be two pairs with one pair above the other. The space between a single pair should not be less than ½-in. ; if provided with a double pair of rolls, the upper pair are kibblers spaced up to 2-in. apart, and the lower pair of smooth rolls are closely spaced to a minimum of $\frac{1}{32}$-in. The kibblers grip and crush the clay sufficiently for fine reduction by the lower rolls, from which it passes in thin sheets.

Screening.—Clay or shale after being ground is generally passed through a screen to ensure that only fine, well graded material is passed forward for moulding. The coarse material retained on the sieve is returned for further grinding.

De-airing.—As is implied, de-airing means extracting air, and is a process which has been recently introduced into this country and applied to certain clays and shales prior to the moulding operation. During the grinding and pugging processes air is introduced between the fine particles. This entrapped air reduces the plasticity of the clay, preventing the mass from becoming thoroughly homogeneous, and causing defects such as blisters, laminations and cracks (see p. 14). The removal of the air therefore increases the workability of the clay and prevents the development of these defects. A de-airing machine simply consists of a chamber to which a vacuum pump is connected. The fine particles of clay or shale are forced into the chamber and the air is extracted as the material proceeds to the moulding machine.

De-airing has been particularly successful in connection with the manufacture of wire-cut bricks (see below), where the complete plant may consist of a pug mill or an *auger machine* with a *shredding plate*, a de-airing chamber, and a second auger which conveys the clay from the chamber and forces it through the *die* to the wire-cutting machine. An auger machine is a horizontal pug mill with a powerful metal screw or worm instead of the shaft with blades. The extruded clay as it leaves the die is in the form of a continuous band having smooth surfaces and sharp, well defined arrises.

Grog, which is burnt waste bricks or burnt clay ground to a powder, is sometimes added to the raw clay in the mill to reduce shrinkage of the bricks during the drying and burning processes.

2. MOULDING.—The prepared clay or shale is machine-moulded by either the (*a*) wire-cut or (*b*) pressure processes, or it may be moulded by hand.

(a) *Wire-cut Process*.—The clay or shale, in the form of a continuous plastic band or column, is propelled from the pug mill or auger over oiled rollers to the *cutting table*. The exit, called the *die* or mouthpiece, is lubricated with water, steam or oil to reduce friction and ensure uniform movement of the column, and is approximately 9¾-in. by 4⅝-in. ; this size is variable, depending upon the shrinkage of the material, which may be ¾ to 1-in. per ft. and which occurs during the drying and burning processes.

The usual type of cutting table consists of a frame containing several wires at a distance apart equal to the thickness of the bricks plus the shrinkage allowance, and is shown in the sketch A, Fig. 1. These wires are kept taut by means of screws. As the end of the column reaches the stop, the frame automatically moves forward and the wires cut the column transversely into brick slabs ; these are pushed forward, placed on barrows and wheeled to the drying floor. In other type of cutting table the frame is fixed and the column, which has been cut to length, is pushed forward past the wires. The frame in another type rotates and the wires divide the column by a downward cut. In one of the latest machines two columns are extruded, and two cutting tables can produce 5,500 wire-cuts daily. As the column leaves the die a small roller under it impresses the trade mark of the firm on the clay at brick thickness centres.

(b) *Pressure Process*.—The prepared clay is automatically fed into rectangular metal die-boxes or moulds which are the size of a brick plus shrinkage allowance. Two of many machines used for this purpose are shown diagrammatically at B and C, Fig. 1. The horizontal rotary table of machine B contains a number of moulds which are brought in turn under the plunger ; the latter charges the moulds with clay and consolidates it under great pressure ; as the table rotates the pressed brick slabs are automatically pushed upwards clear of the moulds and removed. In the press C the clay in the mould or die-box is consolidated as the plunger descends. Some bricks are passed through two presses, the second press producing a better shape and further consolidation. After consolidation the slab is removed either by an upward movement of the base or by the dropping of the sides, which in one type of mould are hinged at the bottom and collapse outwards.

At one works, referred to on p. 10, the clay, after being ground and screened, passes on to a moving steel belt which traverses a huge kiln and feeds the moulding machine which presses four bricks at a time and is capable of moulding 2,600 bricks per hour. This machine travels on rails and is brought opposite the empty chambers of the kiln in turn and into which the moulded bricks are passed direct.

Wire-cut bricks for facings are often *re-pressed* to consolidate them and render their arrises sharp and square. Both types of presses, B and C, are suitable for this purpose, that at B having moulds with collapsible sides which become vertical as each box comes under the plunger. Spraying oil over the bricks facilitates their removal.

Hand-moulding Processes.—Although bricks can be made more cheaply and much more quickly when machine-made, hand-moulding is far from being an obsolete process. On the contrary, the output of hand-moulded facings is increasing, as these are still considered to be best on account of their rich texture, beautiful colouring and durability. Purpose-made bricks which depart from standard sizes, and clay blocks of special shapes to meet specific requirements,

are hand-moulded. Except in certain districts, comparatively few common or *stock*[1] bricks are now moulded by hand.

The clay or shale is prepared by any of the methods described on pp. 2 and 3. In addition, *souring* or ageing the clay is sometimes resorted to. This merely consists of storing the plastic clay, for a period varying from one day to several weeks, in one or more cool chambers to ensure a uniform distribution of the water throughout the mass and the decomposition of any organic matter. This results in an increase in the plasticity and workability of the paste, and assists in preventing the development of cracks, blisters and other defects.

There are two methods of shaping bricks by hand, namely, (*a*) sand-moulding and (*b*) slop-moulding.

(a) *Sand-moulding*.—The wood-mould, shaped as shown at A, Fig. 2, has neither top nor bottom and is usually lined with brass or iron; its internal dimensions are those of the finished brick plus allowance for shrinkage ($\frac{3}{4}$ to 1-in.). This is called an *open-mould* or *stock-mould*, as distinct from a *box-mould* which has a fixed bottom and is used for special bricks.

The moulding operations are done on a wood bench or *moulding stool*, which is about 6-ft. long by 2-ft. wide by 3-ft. high. A " stock " of clay of the correct consistency, flattened on top, and a heap of sand are placed conveniently to hand on or near to the bench. The moulder sprinkles sand on a portion of the table and the inside faces of the mould (hence the name applied to the process) to prevent adhesion and facilitate the subsequent removal of the clay slab. Meanwhile an assistant (known as the " clot-moulder ") cuts a portion of clay from the stock and kneads it into a rectangular " clot " which is about one-quarter larger than the mould. The moulder takes the clot, throws it into the mould and completely fills it by pressing the clay down with his fingers. The edge of a *strike* (a wood straight-edge which is dipped in water) is drawn across the top to remove the superfluous clay and level the surface of the slab. Finally, the moulder lifts the mould, and with a twist of the hand turns the slab on to a flat piece of wood called a *pallet board*. The slab is removed by a boy to the floor of the drying shed.

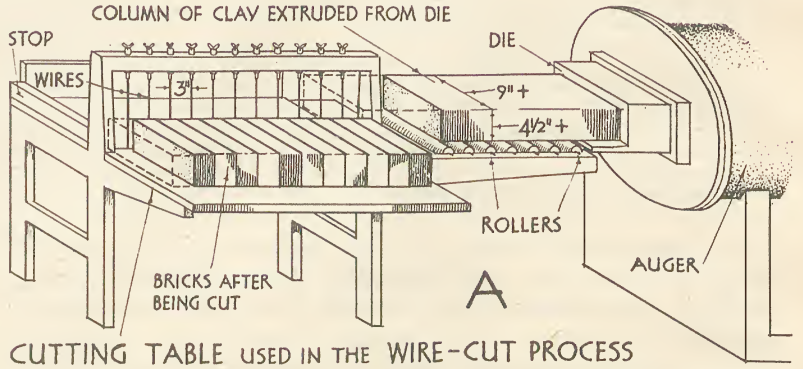
These bricks are often moulded on a piece of wood called a *stockboard*, which is nailed to the top of the bench. It has a raised centre or *kick*. The kick and stockboard are covered with brass as shown at B, Fig. 2. Four metal pegs are driven into the table, one at each corner of the stockboard, and the mould is placed upon them as shown. The thickness of the brick is regulated according to the extent to which the pegs are driven. The kick forms the characteristic frog in the bricks.

Approximately 1,000 bricks per day can be moulded by this method by a moulder and assistants.

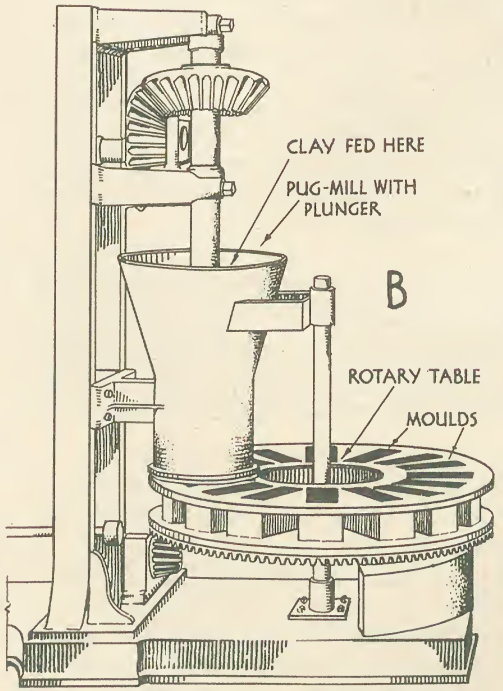
Ornamental bricks and those of special shapes are sometimes moulded from

[1] " Stock " is a term which originally denoted hand-made bricks moulded on a stock-board (see Fig. 2). It is now loosely applied and generally indicates common wire-cuts.

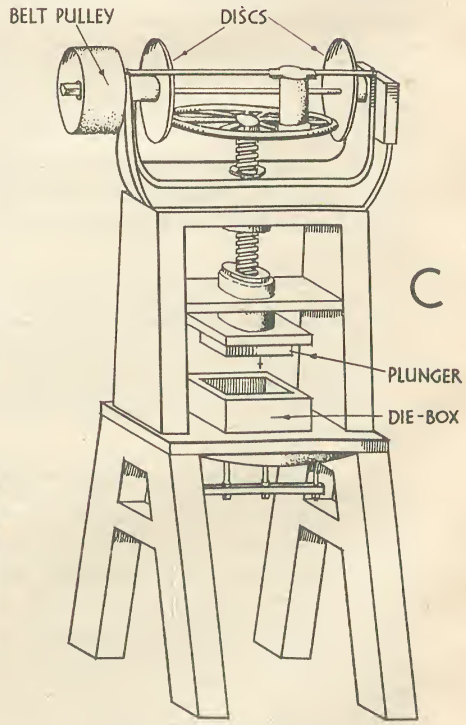
SKETCHES OF BRICK MOULDING MACHINERY



CUTTING TABLE USED IN THE WIRE-CUT PROCESS



ROTARY PRESS

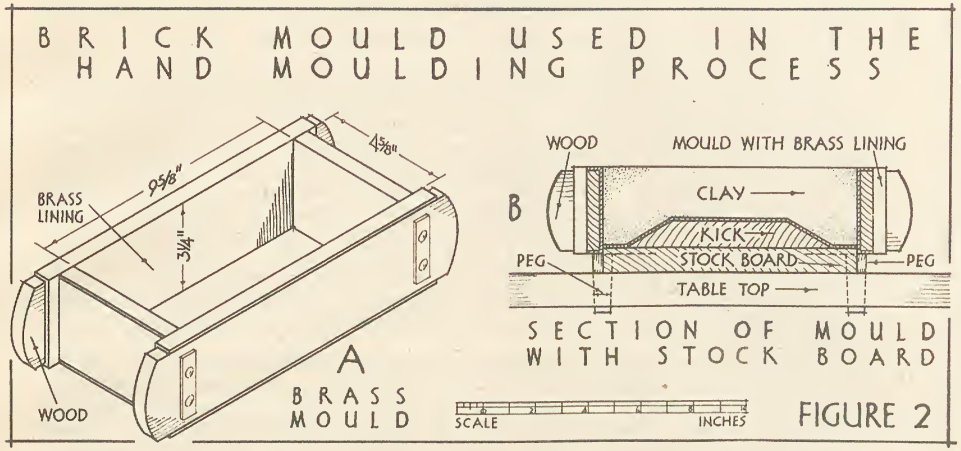


BELT-DRIVEN PRESS

USED IN THE PRESSURE PROCESS

NOT TO SCALE

FIGURE 1



wire-cut and pressed green bricks which are used instead of clots to fill the moulds.

(b) *Slop-moulding.*—This method is now rarely employed. The clay used in this method is more plastic than that used for sand-moulding. Sand is sprinkled on the prepared portion of the table or stockboard. The mould, entirely of wood, is dipped into a trough of water (provided on the bench) and filled with a clot as above described. As the bricks are not sufficiently stiff to permit of their immediate removal on a pallet, the full moulds are taken to the drying floor and there turned out.

3. DRYING.—With exception of common bricks made by the semi-dry process (see p. 2) and certain pressed bricks moulded by the stiff-plastic process (p. 2), bricks must be dried before being placed in the kiln. This applies particularly to those made by the plastic process (p. 2), where the water content may exceed 25 per cent. Drying is effected by (*a*) artificial and (*b*) natural means.

(a) *Artificial Drying.*—The chief heating mediums are steam, direct heat from fires, and waste heat from kilns and boilers. The dryers include the (i) hot floor, (ii) shed, (iii) chamber and (iv) tunnel types.

(i) *Hot Floor System.*—This is commonly employed for drying plastic (wire-cut) bricks. The floor is usually that of the building in which the bricks are moulded and should be adjacent to the kilns. It consists of either steel plates or concrete slabs which cover conduits in which the steam pipes are laid. The steam is controlled by valves in order that the temperature may be regulated to suit the bricks. The steam may be generated from the boiler which provides the power for the crushers, grinding mills, etc.

When direct heat from coal or coke fires is the medium, a number of long flues are constructed immediately under the floor. The flues are about 18-in. square and are parallel to each other at about 8-ft. centres. Each flue is slightly inclined upwards from a fireplace at one end, and the upper ends are connected to a transverse flue which delivers into a chimney.

If waste heat from the kilns is used, the flues under the drying floor are arranged as last described, except that their lower ends are connected by a transverse flue which is connected to the kilns. The flow of gases from the kilns is controlled by a fan at one end of the upper transverse flue.

The bricks from the moulding machine or bench are preferably placed on end on the hot floor, with a space between each, when the heat gradually dries them from the bottom upwards. If the bricks are not stiff enough to permit of this, they are placed on bed on the floor. The time taken to dry bricks varies. Some bricks may be taken on barrows direct to the kiln after being left on the hot floor for one day only, whilst others may require five days before they are fit for removal to the kiln.

(ii) *Shed or Room Dryers.*—A shed is a 30 to 40-ft. wide single storey building containing *racks*. A rack is approximately 2-ft. wide and has ten or more shelves of narrow battens upon each of which a row of moulded bricks is "finger-spaced" on edge. The shed is heated by steam pipes, stoves or a hot floor. Drying is comparatively slow and somewhat irregular.

Sometimes the space above a continuous kiln (see p. 6) is partly utilized to store bricks which are dried by heat from the kiln.

(iii) *Chamber Dryers.*—A shed is divided into several chambers, each about 4-ft. wide, 8-ft. high and of variable length, with a door at each end. The bricks are placed, with a space between each, on loose narrow shelves or on cars. One type of car consists of a bogie (which runs on a track) having a metal frame or rack which supports loose pallet boards that are about 4-ft. long. Each board is loaded with a row of ten or more bricks as they are moulded and placed on edge with a space between. Another type consists of a bogie on the base of which is stacked *stool pallets*. The latter are narrow wood shelves, with 8-in. high end supports, for receiving the moulded bricks which are placed on edge. When rack-cars are used, each drying chamber has longitudinal bearers fixed to the side walls for their entire length and at about 12-in. intervals; these support the loaded pallet boards as they are removed from the cars. Stool pallets are stacked one above the other in each chamber. Loaded cars may be wheeled into the chambers in which they remain until the bricks are dry. The heat must be applied very gradually, otherwise the bricks will warp and crack.

In some dryers the bricks are gradually heated in a saturated atmosphere until they reach a temperature of about 90° F. The humidity is then reduced by the admission of dry air, and the temperature is increased as required. This greatly minimizes damage to the bricks.

(iv) *Tunnel Dryers.*—This type of dryer resembles the tunnel kiln shown in Fig. 4 and described on pp. 10 and 11. As the loaded cars traverse the tunnel, which is about 100-ft. long, hot air (steam or waste gases) enters at the unloading end, and the current is caused to flow towards the loading end by means of a fan. The rate of drying varies, but generally a car of dried bricks is removed and one of green bricks is added every hour. The tunnel dryer may be operated intermittently like a chamber dryer, it being filled with loaded cars of green bricks and the whole of them being removed after the drying operation has been completed.

(b) *Natural Drying.*—Whilst artificial means of drying is now generally adopted, bricks must be dried naturally if heat is not available. Natural drying is usual where clamp-burning (see p. 11) is resorted to and in yards where the output is small. A well ventilated shed may be used, in which the bricks are stacked on racks and dried by the circulation of un-heated air.

Alternatively they are hack-dried. A *hack* is simply a long double row of green bricks which are stacked to a maximum height of approximately 3-ft., depending upon the softness of the bricks.

The hack-ground is level and well drained. There is a space of about 9-in. between each *line* or *blade* of bricks forming a hack; the bricks are placed on edge at ½-in. intervals to a height of from five to eight courses, the bricks in one course bridging the spaces between those in the course below. One course, which may be 200-ft. or more in length, is completed first to allow the bricks to stiffen before the next course is laid. The hacks are spaced at about 3-yds. apart and should run in a north-south direction so that both sides will be exposed to the sun. The bottom course is placed on planks or hollow rectangular tiles or 2-in. thick layers of sand, breeze, etc. As a temporary protection the top of each hack is covered with a series of portable light wood " caps " which are about 6-ft. long with sloping sides in the form of a roof. The sides are also protected by hurdles or screens called *loo-boards*; these are about 6-ft. long and 3-ft. high. This temporary protection is removed during favourable weather, but the hacks should be covered immediately when necessary, otherwise much damage to the bricks may be caused. The bricks are *scintled* when half dry, *i.e.*, they are set diagonally with a 2-in. space between each and with alternate courses reversed.

As bricks containing moisture are readily damaged by frost, hack-drying can only be carried out during six months of the year, from April to September inclusive. The process is extremely slow, the bricks taking from three to six weeks to dry, depending upon the weather and the nature of the clay.

4. BURNING.—This is the final process in brick manufacture. Permanent kilns are chiefly used for burning bricks, although clamp-burning (see p. 11) is still adopted in certain parts of the country. Kilns may be classified into (*a*) intermittent, (*b*) continuous and (*c*) tunnel.

(a) *Intermittent, or Periodic or Single Kilns.*—These are permanent structures and may be divided into (i) down-draught, (ii) horizontal draught and (iii) up-draught kilns, according to the direction of the fire.

(i) *Down-draught Kiln.*—This is the most efficient form of intermittent kiln, and it is the only type adopted to any extent in this country. Even in works having large outputs, it is not unusual to find that the common bricks and certain facings are burnt in a continuous kiln (see next column), whilst best class sand facings and blue bricks are burnt in a down-draught kiln, as the heat which influences the colour can be better controlled in the latter.

The section of a down-draught kiln is shown at T, Fig. 3. That adopted for bricks is usually rectangular, although circular kilns for ware goods (see Chapter Two) are common. The capacity varies from 20,000 to 40,000 bricks. The rectangular chamber has four walls and an arched top which incorporates a heat-insulating ring composed of porous bricks (probably made of a fossil earth known as *kieselguhr*); this reduces the amount of heat transmitted through the structure and thus effects a saving in fuel. The kiln is lined with fire-bricks. Fireboxes are formed at intervals, and a special feature is the continuous screen wall, called a *flash-wall* or *bag-wall*, constructed parallel to and about 9-in. from the inside of each long wall. The heat from the fuel (which is usually small coal called *slack*) thus passes upwards to the arch, which deflects it down through the openly stacked green bricks (see p. 7), the gases escaping through perforations in the floor to a horizontal flue connected to a tall chimney. The screen walls are perforated at intervals near the bottom to allow sufficient heat to pass direct to the lower portion of the stack during the drying process. An opening or *wicket* is provided at one end through which the kiln is filled and emptied. This is bricked up with a temporary wall after the green bricks have been set, and the outside of this wall is luted with clay.

Glazed bricks and certain red bricks (in addition to terra-cotta, etc.) must not be exposed to the direct flames from the fires, otherwise they would be damaged by the gases, dust, etc. Such bricks are heated in *muffle kilns*. This type of kiln consists of an outer rectangular chamber and an inner compartment. A simple form has a fireplace at one end of the chamber and a horizontal main flue, extending the full length, at the floor level. Cross walls at intervals are arched over this flue and these support the inner shell comprising firebrick bottom, sides, top and one end. There is a space between the inner shell and outer structure so that hot gases from the fire can completely traverse it before escaping through openings in the outer roof into an upper horizontal flue extending the full length. The bricks are stacked in the inner compartment and the open end is built-up and daubed with clay. Thus, these bricks are heated entirely by the heat transmitted through and radiated from the firebrick shell.

Sometimes six or more down-draught chambers are constructed to form what is known as a *semi-continuous kiln*. This type provides for the waste heat from one chamber being utilized to dry and heat the bricks in others. Thus, after chambers 1 and 2 have been loaded and the fire in No. 1 lighted, the heat not required passes through holes in the floor of No. 1 chamber, along a flue to an opening (controlled by a damper) in the division wall and over a flash wall into No. 2 chamber, where it circulates round the green bricks before entering the main flue to the chimney. The fire in chamber 2 is maintained, chamber 3 is loaded and the bricks in the latter are gradually heated by the waste gases from No. 2. Each chamber is progressively heated in this manner until the final one is reached. An economy in fuel thus results.

(ii) *Horizontal Draught or Newcastle Kiln.*—Comparatively few of these are now in operation, it having been gradually replaced by the continuous type of kiln. It is a rectangular building with an arched top, and is approximately 15-ft. wide and not more than 30-ft. long. The fireplaces are arranged at one end, together with a perforated flash-wall, and a chimney is provided at the opposite end. The gases traverse horizontally and pass into the chimney at the floor level. A wicket in one or both long walls is formed to permit of loading and unloading.

(iii) *Up-draught or Scotch or Score Kiln.*—This is the most primitive form and is now almost obsolete. It is rectangular on plan, having three permanent brick walls and a temporary end wall; there is no roof, the top being open. The size is roughly 25-ft. by 16-ft. by 10-ft. high. Fire-openings are provided at intervals in the side walls at the ground level. Coal fires are gradually applied after the kiln has been loaded, and when the bricks are dry the top is closely covered with old bricks; these and the temporary end wall are daubed with clay paste. Hot fires are now maintained for two or three days, after which they are damped down and the bricks are allowed to cool. The heat is irregular and consequently there is a large proportion of over-burnt bricks at the bottom and under-fired bricks at the top.

Intermittent kilns are not economical, as the walls have to be heated up at each setting of the kiln, and this results in a heavy fuel consumption.

(b) *Continuous Kilns.*—This type, evolved from the intermittent and semi-continuous kilns, is most suitable for large and regular outputs. It is so called because the operations are uninterrupted, each chamber in turn being loaded, dried, burnt, cooled and emptied, and the waste heat is utilized to dry and pre-heat the green bricks. The kiln is thus economical in fuel consumption.

The structure consists of walls of ordinary brickwork, lined with firebricks jointed with refractory cement, the top is generally arched and lined with purpose-made firebricks, and the floor is usually constructed of hard bricks bedded on sand or concrete. The kiln is divided into compartments or

chambers. The divisions may be temporary (see C, Fig. 3) or permanent (see M). The number of compartments varies; twelve is considered to be a minimum, fourteen and sixteen are common, whilst the largest kiln in this country (see p. 10) has 224 chambers. The length of a chamber is usually from 12 to 16-ft., the width varies from 9 to 16-ft., and the height to the crown rarely exceeds 9-ft. Best results are obtained if the total length of the chambers is not less than 200-ft. to permit of the efficient control of the various operations. Each chamber has an opening (known as a *wicket* or *door gap*) in the external wall for loading or "setting" and emptying or "drawing" the bricks; it has a flue, controlled by a damper, to convey the used gases to the main flue and thence to the chimney. In a more modern kiln, and especially those used for producing facing bricks, each chamber is connected to a hot-air flue (see p. 8). Small coal or slack is commonly used as fuel. This is fed through *feed-holes* situated in the top of the kiln, and these are preferably of fireclay blocks covered with movable metal airtight caps. The capacity of a chamber varies; the smallest will hold about 8,000 bricks, whilst a very large chamber will accommodate 40,000 or more bricks. It is customary for one chamber to be drawn and one to be filled daily. The rest of the kiln is divided into (1) drying, (2) pre-heating, (3) firing and (4) cooling zones (see U, Fig. 3).

(1) *Drying or Steaming or Water-smoking Zone.*—A brick, even after being treated in a dryer, has a comparatively large water content which often exceeds one-sixth of its dry weight. The process of eliminating this water is an important one, for, if not carried out gradually, the bricks will crack and their strength be considerably reduced by the formation of steam within the small voids or pores of the material. The bricks in the drying chambers of the kiln are gradually heated to a temperature of 120° C. (250° F.) by the admission of hot air from the pre-heating chambers. This hot air should be free from gases, such as sulphur dioxide, otherwise the bricks will be discoloured by a deposition on their exposed surfaces of a film called *scum* or *kiln-white* (see p. 14). The waste heat from the firing chambers should not be used for drying purposes in kilns in which facings are produced, as this contains gases which cause discoloration (see p. 8). Large volumes of steam are produced during the drying process, and for the production of good coloured bricks this steam must be rapidly removed through flues (see p. 14) to avoid condensation on the bricks. The length of the drying zone depends on the length of the chambers and the draught created by the chimney, but in a fourteen chamber kiln the zone usually comprises two chambers, and three will be required in a sixteen chamber kiln (see U, Fig. 3).

(2) *Pre-heating Zone.*—The bricks in this zone are gradually brought to a dark-red heat (600° C.), during which the chemically combined water is set free and removed, and then the burning is carefully controlled until the temperature is increased to approximately 950° C. During the latter stage the iron and other compounds are oxidized and the colour of the bricks is influenced; the burning must therefore not be hurried, otherwise the bricks will be discoloured and hearting (see p. 13) will result. The length of the pre-heating zone is usually equivalent to four chambers (see U, Fig. 3).

(3) *Firing Zone.*—The bricks are vitrified during the final heating which takes place in this zone in which the maximum temperature may reach 1,100° C.[1] The number of chambers in this full-firing zone is two and three in a fourteen and sixteen chamber kiln respectively (see U). Coal is added through the feed-holes every quarter of an hour, and fuelling of the kiln is confined to them, the chambers in the drying and pre-heating zones having been heated by waste heat from the cooling zone. The stoking is generally done by hand, although the employment of automatic feeders which discharge the required quantity of coal at regular intervals is increasing. The durability of the bricks depends upon the firing of the kiln at this stage; excessive temperature will cause the bricks to lose their shape, and under-burning will reduce their strength.

(4) *Cooling Zone.*—This usually consists of four chambers, as shown at U, although in the larger kilns the length of the zone is increased and the risk of damage, such as cracking, is correspondingly reduced. The temperature of the bricks in the unloading chamber, which adjoins the cooling zone, should be sufficiently low to enable them to be handled comfortably.

SETTING.—There are several different arrangements of setting the green bricks in a kiln, much depending upon the stiffness of the bricks and the type of kiln. One form is to stack them on edge in a series of *bolts* or rows, 9-in. thick, alternately as headers and stretchers and about ¾-in. apart. Another arrangement, suitable for a continuous kiln, is shown in the section at A, Fig. 3. This shows three courses of bricks (headers) on edge, "finger-space" (about ¾-in.) apart. A course of stretchers is placed upon these, followed by alternate double courses of headers and single courses of stretchers. Vertical flues, called *fire-columns*, are formed in the stack under the feed-holes. These extend from top to bottom, are about 5-in. square and serve as combustion spaces and for ashes.

The following is a description of some continuous kilns, including the Manchester, Zigzag, Hoffman and Habla kilns.

MANCHESTER KILN[2] (see A, B and C, Fig. 3).—That shown is a simple form of the Manchester kiln, and is suitable for the burning of common bricks.[3] It consists of two long compartments, separated by a longitudinal wall, and whilst it has no permanent division walls, it is divided into chambers by paper "partitions" (see p. 8), and it is therefore called a fourteen chamber kiln. Each chamber accommodates 8,000 bricks, and as one chamber of burnt bricks is emptied per day, the weekly output is approximately 50,000 bricks, which is considered to be the minimum for a continuous kiln. Whilst a smoke flue, controlled by a damper, can be provided for each chamber, the plan shows that one damper serves chambers 1 and 14, and similarly another damper is

[1] This varies; thus, for Fletton bricks the maximum temperature may not exceed 850° C.

[2] By courtesy of Messrs Dean, Hetherington & Co., Accrington. This is the smallest and simplest type of continuous kiln built by this firm.

[3] The Manchester kiln, incorporating a hot air flue, is used for the production of facing bricks.

common to both chambers 7 and 8; this is in order to simplify the kiln. The chamber flues are connected to two main flues which lead to a chimney (40-ft. high and 4-ft. internal diameter) conveniently near.

To fire this kiln for the first time, six or seven chambers are set with green bricks and each section is separated by being papered off. Thin brown paper, obtained in rolls, is usually used for this purpose, and this is pasted over (liquid clay, called *slip*, being used as an adhesive) the last completed end face of stacked bricks. The wickets in these chambers, 2 to 7 inclusive, are bricked up with temporary walls, and a small fireplace is prepared in each. A temporary brick wall, shown at H on plan C, is built, and this is prepared with four fireplaces. Fires are lit in these fireplaces and the heat is steadily applied to the bricks in chamber 2. The damper controlling this section is open to allow the steam and gases to escape. When the temporary wall at H gets too hot to the hand, the paper partition separating chambers 2 and 3 will have burnt away. No. 2 damper is then closed and No. 3 damper is opened, thus allowing the heat to pass through chamber 2 to chamber 3, and hence into the main flue to the chimney. This is repeated until three or four chambers are red hot. Coal is then passed through the feed-holes and down the 5-in. square fire columns (see p. 7). Meanwhile further chambers will have been set with green bricks until all of the chambers, excepting No. 1, are filled. The open fires in the temporary wall at H and those in the wickets are maintained until a sufficient body of heat has been built up to light and support combustion of coal fed from the top. The open fires are then stopped in rotation, chamber 1 is set and papered over as described above, and the bricks in chamber 2 are removed. The kiln is now prepared for normal working, when one chamber is emptied and another is filled daily.

After the whole of the chambers have been fired, the following is a normal daily schedule for this kiln, assuming that the direction of the fire is clockwise as shown by the arrow, and that chamber 3 is being unloaded :—

Chamber.	Bricks.		Chamber.	Bricks.	
		Temperature.			Temperature.
1	Drying	25° C. (min.)	10	Heating	700° C. to 120° C.
2	Being set	Cool	11	Heating	
3	Being drawn	Cool or cold	12	Heating	
4	Cooling	50° C. to 1,000° C.	13	Heating	
5	Cooling		14	Drying	120° C. (max.)
6	Cooling		Wickets 2 and 3 are open, remainder are built up.		
7	Cooling		Damper 1 is open, rest are closed.		
8	Firing	1,100° C. (max.)	Paper partition pasted on bricks stacked in chamber 1 on face adjoining chamber 2.		
9	Firing	700° C. (min.)			

The cold air entering wickets 2 and 3, whilst cooling the bricks, gradually increases in temperature, especially when it traverses those in chamber 7 which had been subjected to the maximum temperature the previous day. This supplies the primary heat to burn the coal, which is fed in small quantities every fifteen minutes from the top of chambers 8 and 9. As the hot air proceeds on its travel, it pre-heats the bricks in chambers 10, 11, 12 and 13, and dries and steams those in chambers 14 and 1 before escaping down the branch flue No. 1.

This being a continuous process the operations are maintained in this sequence, but are advanced by one chamber daily. Thus, on the following day chamber 3 is filled and chamber 4 is emptied.

As the whole of the waste heat is utilized to dry the bricks in this [illegible] and as that from the firing chambers may cause discoloration (see p. 14), it follows that the kiln is best suited for the manufacture of common bricks, for which purpose it is most economical. The provision of hot air flues (see below) is necessary for the production of good-coloured bricks.

During slack periods, when the output from half the kiln would be sufficient to meet the demand, it may be used intermittently as follows : Four small fireplaces are constructed in the external end wall of chamber 1, the two openings between chambers 1 and 14 and 7 and 8 are built up temporarily, and the chambers 1 to 7 inclusive are filled with green bricks. Fires in the end fireplaces are maintained until there is sufficient heat to fire coal fed through the feed-holes. Top feeding of the chambers is continued until the bricks are thoroughly burnt, when the half kiln is emptied and re-set.

ZIGZAG KILN (see J, K, L and M, Fig. 3).—This is one type of Zigzag kiln[1] which is divided by permanent walls into fourteen chambers. The fire is drawn in a zigzag direction owing to the position of the openings in the division walls being staggered, causing it to traverse each chamber diagonally.

Each chamber has a transverse *downcast flue* under the floor which is connected to the *main* or *smoke flue* and controlled by a damper from the outside. There is, in addition, a *hot air flue* immediately over the main flue and extending the full length of the kiln. When required, each chamber is connected to this hot air flue by raising the damper controlled from the top of the kiln (see K and dampers 1, 14, 2, etc., at M). As mentioned on pp. 7 and 14, hot gases from the firing chambers must not be used to dry bricks if scumming is to be avoided, and only hot gases from the *cooling* chambers should be admitted for this purpose. Hence the necessity for this hot air flue. In addition to the downcast flue and hot air flue dampers, each chamber has a third or main flue damper immediately over the crown of the smoke flue and controlled from the top of the kiln (see K and dampers 10, 5, 9, etc., at M). These, together with the downcast flue dampers, are opened wholly or partially as required in the drying chambers for the rapid removal of the steam.

The process is continuous, at least one chamber being loaded and one unloaded daily. The daily schedule of the operations varies according to the nature of the clay, quality of bricks, draught (velocity of the air created by the chimney or fan), length of fire circuit, etc.

The Zigzag is exceptionally efficient for the following reasons : (1) It can be effectively controlled; (2) it produces bricks of first quality, comparatively free from undesirable discoloration and other imperfections enumerated on pp. 13 and 14; and (3) the fuel consumption is relatively low.

HABLA KILN.—This has several features which resemble the Zigzag kiln. The plan is similar in that the *trace holes* (openings in the partitions) are staggered, causing the fire to take a zigzag course, but these partitions, instead of being permanent as in the Zigzag kiln, consist of dried bricks (without mortar) and are therefore temporary.

For the production of common bricks the kiln has not a permanent top, and it is therefore classified as of the " archless " type. After the loading chamber has been set, it is covered with either two courses of bricks laid close together with a layer of sand or ashes on top, or concrete slabs with metal trays containing kieselguhr, a highly porous earth which serves as a heat insulating material. The kiln is fired by pulverized

[1] From details supplied by Messrs John Jones & Sons, Buckley, Chester.

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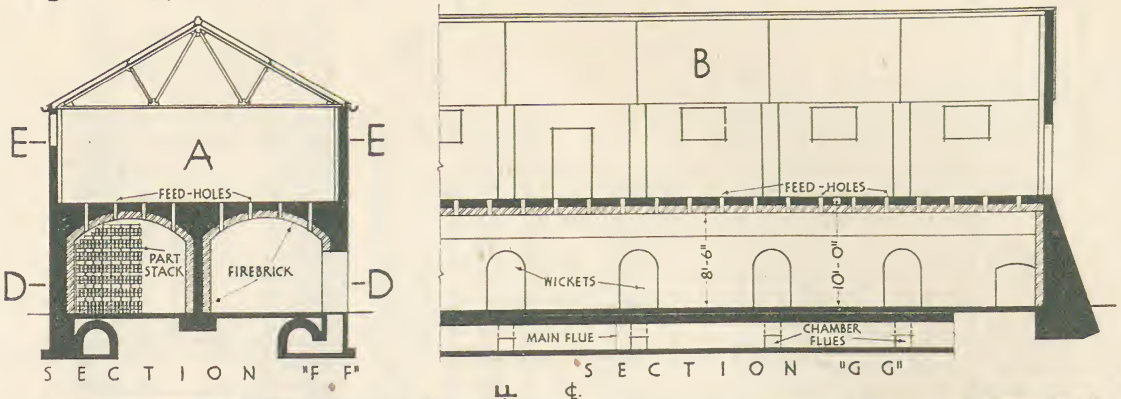
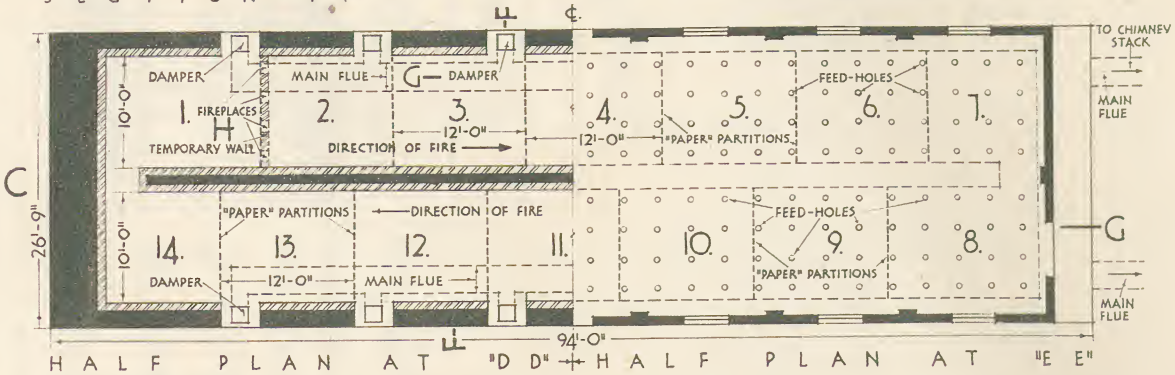


S E C T I O N "F F"

S E C T I O N "G G"



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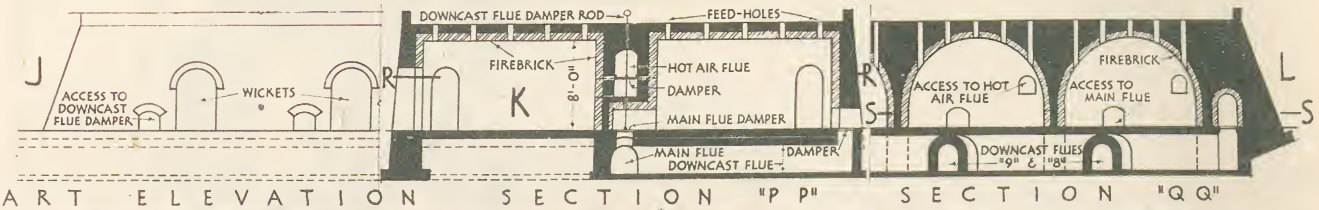

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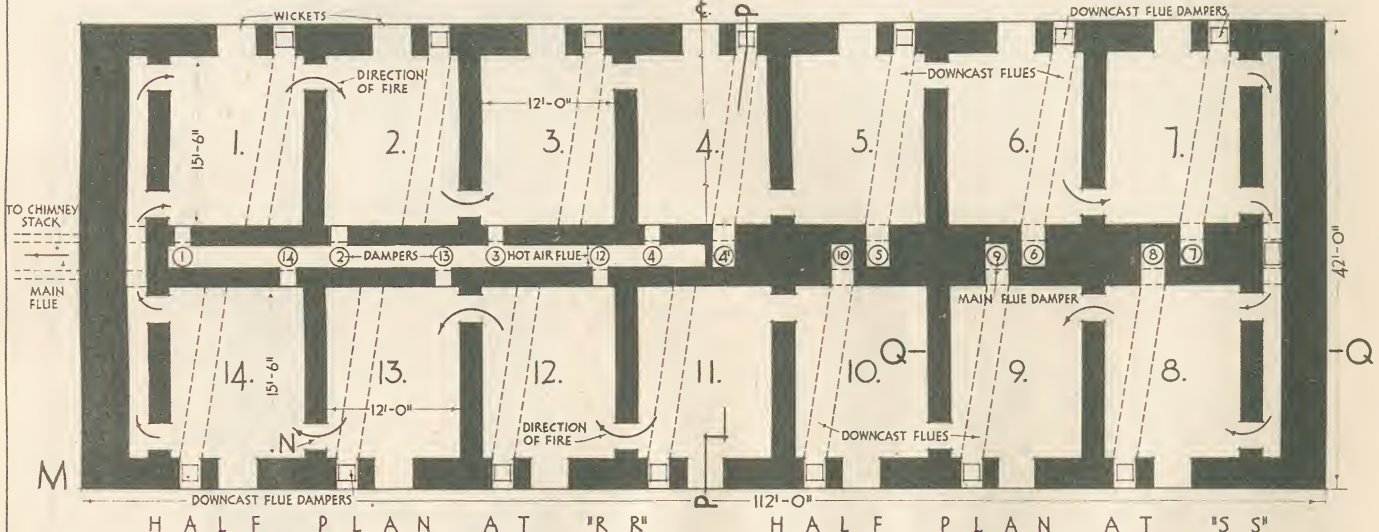
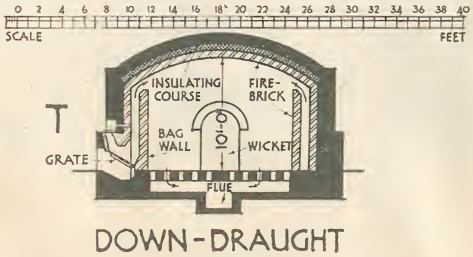
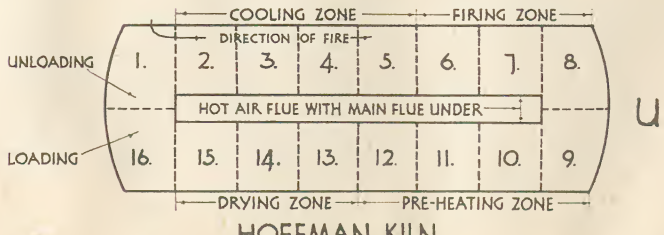


H A L F P L A N A T "R R" H A L F P L A N A T "S S"

Z I G Z A G K I L N



DOWN-DRAUGHT KILN



HOFFMAN KILN
NOT TO SCALE
SHOWING VARIOUS ZONES

FIGURE 3

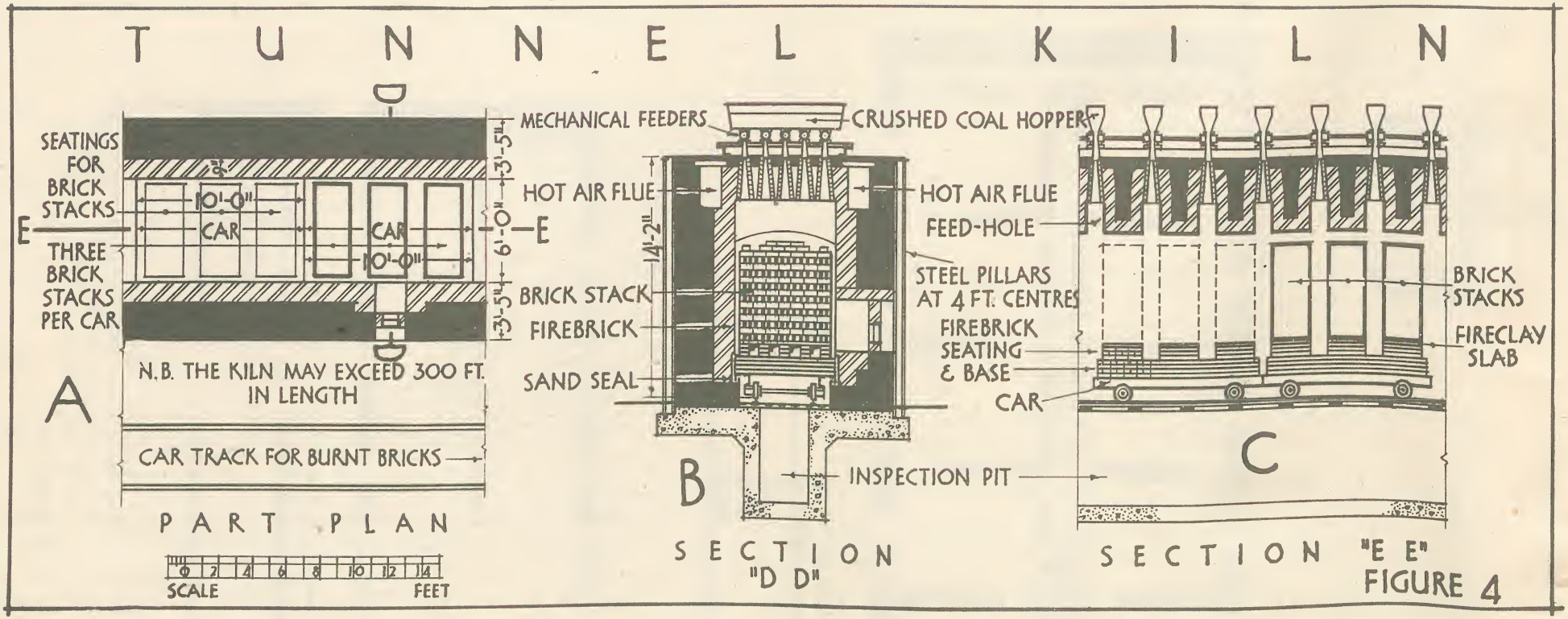


FIGURE 4

coal passed through feed-holes provided in the temporary top. It has main and hot air flues. An arched permanent top is best if facings are to be produced.

The Habla kiln, like the Zigzag kiln shown in Fig. 3, has a long length of travel, which facilitates the control of operations, and it is relatively cheap to construct.

HOFFMAN KILN.—This is probably the best known kiln of the continuous type. The original kiln was circular on plan, the chambers (separated by paper partitions) being placed round a central tall chimney. This kiln has been improved, and a plan of the later type of Hoffman kiln is shown in the line diagram at U, Fig. 3. The number of chambers varies, but the largest of this type, used for the burning of Fletton bricks, has no less than 224 chambers.[1] In addition to the main flue which takes the products of combustion from each chamber, it has a central hot air flue to which are connected branch flues from the chambers, so that hot air from the cooling chambers may progressively be admitted to dry the bricks. Each chamber is further provided with a flue in the top to allow the steam to escape during the preliminary drying operation. One chamber is filled and another is emptied daily, as described on p. 8. Common bricks, together with a proportion of selected facings, are produced in this kiln.

[1] This kiln is at the works of Messrs The Marston Valley Brick Co. Ltd. Its length is 3,250-ft. Each chamber has a capacity of 33,000 bricks. Fourteen chambers are subjected at the same time to the maximum temperature with fifteen chambers between each. Hence it is equivalent to fourteen 16-chamber kilns and the *weekly* output is approximately 3¼ million bricks.

(c) *Tunnel Kilns.*[1]—This kiln, shown in Fig. 4, is a brick structure which is traversed by cars or trucks upon which the bricks are stacked. The kiln may be from 300 to 450-ft. long, its internal width varies from 5 to 6-ft., and its height to the crown of the arch is approximately 10-ft. The kiln has three zones, *i.e.*, pre-heating, firing and cooling, thus for a 300-ft. kiln these are approximately 130-ft., 100-ft. and 70-ft. long respectively. The firing zone and part of the cooling zone are lined with firebrick, and the walls of the former are constructed with a 9-in. thick layer of insulating material between the lining and the outer brickwork; this insulation protects the latter and conserves the heat. A metal door is provided at each end of the kiln.

The metal cars are 10-ft. long, and their bases are protected by three or four courses of firebricks. In a siding adjacent to the kiln each car is loaded in three stacks with a space between each; three seatings, each three courses high of firebricks covered with a fireclay slab, are provided on the base to receive the bricks. The approximate number of 3-in. bricks which a car will hold is 2,000. The kiln and tracks for loading and unloading the cars are under cover.

Rows of feed-holes are provided at intervals in the roof of the firing zone, the distance between each row being equal to that between the stacks of bricks. The fuel is crushed coal, and this is fed from hoppers which are placed over mechanical feeders fixed immediately over the feed-holes. Thus the coal dust is fired immediately

[1] By courtesy of Messrs Gibbons Bros. Ltd., Dudley.

it enters the kiln and the larger particles continue to burn as they pass down the spaces between the stacks to the base. The air for combustion, drawn in through the exit by means of a fan, is pre-heated as it passes through the cooling zone, and the temperature, which increases as the draught of air proceeds through the firing zone, is gradually reduced as it traverses over the bricks in the pre-heating zone. The combustion is so complete that little smoke escapes at the fan outlet, and a chimney stack is therefore not required. At the exit end of the cooling zone a vertical air flue is provided which is connected to a horizontal flue that is continued over the arch of the cooling zone, along each side of the firing zone (see B) and over the pre-heating zone arch to a fan which delivers the hot air to the brick drier. Scumming of the bricks is avoided by the provision of a number of waste gas flues at the front end of the pre-heating zone which are connected to a common flue controlled by an extraction fan to withdraw the gases. A sand seal is provided at each side of the kiln throughout its length; these consist of metal channels containing sand through which pass the lower edges of the metal plates fixed at the sides of the cars. The seals prevent loss of draught and protect the wheels and axles of the cars.

The cars are caused to travel on a track for the full length of the kiln by means of a powerful hydraulic ram. The movement is intermittent, the cars being pushed forward at regular intervals to the extent of one-third the length of the car or the equivalent of a stack and one space. This distance is maintained uniformly so as to ensure that the spaces (called *combustion chambers*) between the brick stacks are immediately under the feed-holes. As these spaces extend the full width and height of the stacks, a uniform temperature throughout is ensured and this results in the bricks being uniformly burnt. It takes from two to three minutes to move the load, and the interval between each movement varies from thirty to fifty minutes according to the output required. The rate of travel varies, but for a 300-ft. kiln, the time taken between a car entering and leaving the kiln is approximately three days and the weekly output is about 160,000 bricks. The working of the kiln is very flexible as it can be readily speeded up or slowed down as occasion demands by regulating the rate of travel and the amount of coal supplied by the mechanical feeders. As each car of finished bricks emerges from the kiln, another car of green bricks enters the charging end.

The advantages claimed for the tunnel kiln are: (1) The bricks are evenly burnt, and it is therefore particularly suited for the production of first-class facings; (2) the output is regular and only a small percentage of bricks are damaged in the process; (3) low maintenance costs; (4) flexibility of working; and (5) on account of the complete combustion which results, there is no smoke nuisance and the conditions of employment are improved, as the kiln is not entered to load and unload the bricks.

The disadvantages of this type of kiln are: (1) The relatively high initial cost, and (2) the additional cost of providing power for the ram, fans, etc.

Temperature Control in Kilns.—The temperature in kilns in which first-class facings are produced is sometimes controlled by the use of either *Segar cones* or a *pyrometer*.

Segar cones are small L-shaped pieces made from special clays, having a flat base with a vertical leg, and are tested to bend at certain temperatures. Thus, a "No. 022 cone" will bend (*i.e.*, the leg will gradually collapse until the top touches the base) when subjected to a temperature of 600° C., whilst a "No. 10 cone" will do likewise at 1,300° C. Generally three cones of the desired "temperature resistance" are placed in different parts of the kiln, and in positions in which they will be seen through spy-holes in the walls. Firing ceases when the required temperature in the kiln has been reached, indicated by the bending of the cones.

Electric pyrometers are usually used in gas-fired kilns. Such consists of an electrical conductor (containing a coil of platinum wound round a strip of mica) which is exposed to the heat. This is connected by leads to an electrical system which automatically records temperature movement on a chart, and the rate of firing in the kiln is regulated according to the readings.

Clamps.—A clamp simply consists of a large mass of green bricks stacked, with several intermediate layers of breeze (cinders) as described below, upon a foundation of old bricks. It has neither walls nor roof. Clamp-burning preceded kiln-burning, and it is still adopted in certain parts of the country, particularly in Kent and Essex, where *London stocks* are made. Clamps are also occasionally used at works to provide temporary additional means of burning when the output of the permanent kilns is insufficient to meet heavy demands. The bricks are not uniformly burnt, and whilst a large proportion is satisfactory, those on the outside are underburnt, and those near the *live holes* (see below) and in the heart of the kiln are mis-shapen and cracked owing to the excessive heat.

A clamp is constructed in the following manner: The ground, which should be well drained, is paved with a layer of old bricks, placed on edge. The size of this paving is from 40 to 50-ft. square, although this varies. This paving is slightly dished, rising slightly from the centre to the edges, to prevent the stacked bricks when being burnt from falling outwards. The clamp is built with a series of 3-brick thick walls (called *necks*), and the construction may be commenced either (*a*) at one end or (*b*) down the middle.

(a) *End Clamping*.—The end wall, known as the *upright*, extends the full width of the clamp. It is about 4-ft. 6-in. thick at the base, and is formed with a vertical face internally and a battered face externally. The bottom course consists of old burnt bricks laid scintled (diagonally) on edge with 2-in. spaces between. The second course is also formed of burnt bricks laid on edge, but these are spaced as stretchers. Breeze and coal slack is placed in the spaces between the bricks, and the top is covered with a 6 or 7-in. layer of breeze. The first course of green bricks is laid as headers on top of this layer, the bricks being placed on edge and closely spaced. This is covered with a 4-in. layer of breeze, followed by the second course of raw bricks (stretchers) placed on edge, with a slight space between each. This course is given a 2-in. covering of breeze. The remainder of the wall is formed of alternate courses of headers and stretchers of raw bricks, placed on edge, slightly spaced and with a thin sprinkling of breeze between each course. The number of courses of green bricks is approximately thirty. A 3 to 6-in. layer of breeze is spread over the top course of raw bricks, and this is covered by a course of old bricks, closely set on edge, with the joints luted with clay.

The rest of the clamp is constructed with a series of parallel 3-brick thick walls or "necks," extending its full width, until the opposite end is reached, when an "upright" is built similar to the first with an external batter. These necks are formed exactly like the uprights, having alternate header and stretcher courses of green bricks on a double course of old bricks at the base, layers of breeze and a daubed hard brick finish. The breeze layers are continuous, and the bricks are so arranged that a stretcher course in one neck is opposite header courses in adjacent necks.

In the middle of each end neck a continuous horizontal flue (called a *live hole*) is formed between the double course of burnt bricks forming the base. It is formed by leaving a 9-in. wide space whilst constructing the base. Similar flues (which are 9-in. high) are constructed along the centre of every seventh or eighth neck. Dry brushwood is placed in these flues and this is covered by the 6-in. layer of breeze.

(b) *Middle Clamping*.—In this system the upright is constructed down the centre to the full extent of the clamp. It is built in a similar manner to the end uprights described above, except that it has a batter on each face, and a 9-in. by 9-in. horizontal flue is formed in the middle of the base for its entire length. The necks are formed on either side of the upright and with the faces parallel to the batter. Three transverse horizontal flues (one in the centre and one at about 7-ft. from each end) are formed in the base whilst the necks are being built, and these are connected to the central live hole. These cross flues are filled with brushwood.

It is usual to construct a wall of old bricks on each face of the clamp and extending the full height. This is 9-in. thick at the base and 3-in. at the top. These walls are daubed over with clay, except where holes have been left for the admission of air.

The clamp is fired by lighting the brushwood in the flues. Gradually the breeze

begins to burn, and the fire passes upwards until the whole clamp is burning. London stocks and most of the bricks burnt by this primitive method are made of clay to which sifted breeze has been added; alternate layers of clay, breeze and washed chalk are stacked and allowed to weather (see p. 2); this is subsequently mixed and the breeze thoroughly incorporated. Such bricks therefore contain fuel, and the clamp continues to burn for two and a half to six weeks until this breeze has been consumed. Little attention is needed whilst the clamp is burning. If the fire is proceeding too quickly, the air holes are stopped to reduce the draught. Protection is sometimes afforded by boarded screens fixed on the windward sides.

SIZES OF BRICKS.—The sizes of bricks have been stated in Vol. I (p. 3). According to the British Standard Specification, No. 657—1936, the bricks laid dry shall measure as follows[1]:—

(*a*) Eight bricks laid end to end, in contact, in a straight line shall have a maximum length of 71-in. and a minimum length of 69-in.

(*b*) Eight bricks laid side by side, in contact, in a straight line shall have a maximum length of 34-in. and a minimum length of 33-in.

(*c*) Eight bricks laid on edge, in contact, in a straight line shall have a

Maximum length of $16\frac{1}{2}$-in.
Minimum length of $15\frac{1}{2}$-in. } Type 1.

Maximum length of $21\frac{1}{2}$-in.
Minimum length of $20\frac{1}{2}$-in. } Type 2.

Maximum length of $23\frac{1}{2}$-in.
Minimum length of $22\frac{1}{2}$-in. } Type 3.

Thus the standard dimensions of a brick are:

Length (in Inches).				Width (in Inches).			
Mean.	Max.	Min.	Tolerance.	Mean.	Max.	Min.	Tolerance.
$8\frac{3}{4}$	$8\frac{7}{8}$	$8\frac{5}{8}$	$\pm\frac{1}{8}$	$4\frac{3}{16}$	$4\frac{1}{4}$	$4\frac{1}{8}$	$\pm\frac{1}{16}$

Depth (in Inches).									
Type 1.			Type 2.			Type 3.			Tolerance.
Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	
2	$2\frac{1}{16}$	$1\frac{15}{16}$	$2\frac{5}{8}$	$2\frac{11}{16}$	$2\frac{9}{16}$	$2\frac{7}{8}$	$2\frac{15}{16}$	$2\frac{13}{16}$	$\pm\frac{1}{16}$

For snap headers the width and depth shall be as specified above and the length shall be $4\frac{3}{16}$-in. $\pm\frac{1}{16}$-in.

For queen closers the length and depth shall be as specified above and the width shall be 2-in. $\pm\frac{1}{16}$-in. (see U, Fig. 2, Vol. I).

[1] Included by permission of the British Standards Institution.

COLOUR OF BRICKS

There is a wide range of colours of bricks, such as white, grey, brown, red, purple, blue and black, with intermediate shades. Bricks of varying shades, called *multi-coloured*, have within recent years been in big demand for faced work. Some bricks are uniform in colour, whilst others are mottled or irregularly shaded. The colour is influenced by: (*a*) Chemical constitution of the clay, (*b*) temperature during burning, (*c*) atmospheric condition of kiln, (*d*) sand-moulding, and (*e*) staining.

(*a*) CHEMICAL CONSTITUTION OF CLAY OR SHALE.—Iron oxides affect the colour considerably. Thus, clays which produce white bricks have little or no iron present, whilst blue bricks contain at least 7 per cent. oxide of iron. Careful blending of the clays and shales (see p. 2) is responsible for the production of many beautifully coloured bricks, and such colours are permanent.

(*b*) TEMPERATURE DURING BURNING.—Light coloured bricks are often the result of the temperature of the gases in the kiln being too low, or the duration of the maximum temperature being too short, whilst, at the other end of the scale, Staffordshire blue bricks require a temperature which may reach 1,200° C.

(*c*) ATMOSPHERIC CONDITION OF KILN.—Certain white bricks can only be produced if they are protected in the kiln from smoke, whilst dark brown and purple coloured bricks are made by creating a smoky atmosphere in the kiln (see below).

(*d*) SAND-MOULDING.—Sand-moulded hand-made bricks (see p. 4) and pressed bricks which have sand sprinkled over their oiled surfaces whilst being moulded are richly coloured during the burning process. The nature of the sand used for this purpose depends upon that of the clay or shale, and a good deal of experimental work with different coloured sands is often necessary before the desired colour of the facing bricks is obtained.

(*e*) STAINING.—Surface colours may be obtained by adding certain metallic oxides (such as manganese for browns, chromium for pinks, antimony for yellows, copper for greens, cobalt for blues, cobalt and manganese for blacks, etc.) which are crushed very finely and added to the sand sprinkled on the bricks prior to burning. Sometimes water is added to the oxides and brushed on the surfaces. Such colours, unlike those produced by blending (see above), are rarely permanent.

White bricks contain not more than a trace of iron and generally a large proportion of lime.

Cream bricks contain traces of iron and a small proportion of chalk.

Grey bricks are either commons which have been discoloured by scumming (see p. 14) or facings, such as *silver-greys*, which have been stained on the surface.

Buff bricks contain less than 2 per cent. of iron oxide.

Yellow bricks contain magnesia or sulphur (when clamp-burnt).

Red bricks contain at least 3 per cent. of iron oxide.

Brown and *purple* bricks may have a similar iron content to reds, but the difference in the colour is due to smoking and special firing.

Blue bricks contain 7 to 10 per cent. of iron oxide. A blue surface colour is also obtained by pouring coal-tar in the fireboxes of the down-draught kiln (or that of the firing chamber of a continuous kiln) just before the burning process has been completed. This produces a dense smoky atmosphere. The damper is partially closed. This is repeated three times at twenty-minute intervals, when the damper is closed and the chamber is left sealed for at least forty-eight hours. If salt is mixed with the tar the exposed surfaces of the stacked bricks will be glazed. Purple bricks may be produced in a similar manner.

Black bricks contain a similar amount of iron to the blue clay, in addition to certain manganese oxides. This iron, etc., content is responsible for the colour produced when the bricks are burnt. Black colour is also produced as described for blues, except that zinc and not tar is applied to the fires, and twenty-four hours' sealing of the chamber is usually sufficient.

Multi-coloured Bricks.—The diverse range of colours of these bricks is very largely due to (*b*) and (*c*)—see p. 12; the bricks are generally produced in a down-draught kiln (p. 6), as the temperature and smoking are best controlled in this type. The bricks are carefully stacked on *bed* to avoid damage, and so arranged that one end and one face of each is exposed. The kiln is fired as already described until the bricks have been subjected to the maximum temperature for a sufficient period, which varies according to the nature of the clay or shale. A *reducing atmosphere* is then produced in the kiln by restricting the admission of air to the kiln and heavily charging it with smoke. Thus the flue is partially closed by lowering the damper, and dense smoke is caused by charging the fireboxes with coal. Immediately the smoke has abated, more fuel is added to produce a dense smoky condition and, after these operations have been repeated over a period of approximately ten hours, the fireboxes and flue are closed for about four hours. The flue is then opened and the bricks are allowed to cool. Many variations in colour can be obtained in this manner, much depending upon the skill of the operator.

TEXTURE OF BRICKS

There is considerable variation in the texture (or surface finish) of bricks. Thus, machine-made commons and certain facings have smooth faces, whilst hand-made facings cannot be equalled for the richness of their texture ; many machine-made bricks are characterized by roughened surfaces which have been purposely exaggerated. The pleasing texture of hand-made bricks is produced during the moulding operation, the hand-pressing of the clay or shale into the mould and the sand from the sides of the mould, which is stamped into the material, giving an irregular creasing or unevenness to the side and end surfaces. The fine colouring of a mass of brickwork constructed of such bricks, particularly after it has weathered for some time, is enhanced by the light and shade effect produced by the uneven surfaces. Such bricks are expensive, and therefore attempts have been made to imitate this texture and apply it to mechanically made bricks. Some of these attempts have been quite successful, even if the resulting texture is of less quality (chiefly because of the uniformity which results when the depressions or roughness are similar on every brick) than that of hand-made bricks.

The following are some of the means which are adapted to produce a mechanical texture :—

Wire-cut bricks are given a roughened appearance on three faces by a frame containing a horizontal and two vertical wires which is fixed about 1-in. in front of the mouthpiece of the auger (see p. 3). The horizontal wire is stretched across and just slightly below the top of the opening, and the distance between the two taut vertical wires is slightly less than the width of the die. These wires cut the band of clay as it is extruded from the machine, leaving roughened surfaces on the top and sides.

Rustication may also be obtained by plates containing fine projecting wires, one plate being fixed above and two at the sides of the clay column as it issues from the mouthpiece. The points of these wires slightly penetrate at varying depths the moving clay band and scratch the surfaces. Felt covered rollers partly smooth the excessive roughness as the column proceeds to the cutting table.

Hand or mechanical *stippling* is resorted to as an alternative. This consists of scrubbing or dabbing the top and sides of the clay band with brushes having metal bristles. Some of the irregularities are smoothed down by rollers.

A rustic effect can also be produced by *sand-blasting*. Specially selected sand is forced by compressed air through the nozzle of a pipe on to the top and sides of the extruded clay. This produces small depressions on the surface. Rustic pressed bricks can be treated in this manner.

Pressed bricks can be rusticated by using a mould or metal press-box having hinged sides. Relief (raised) patterns are engraved on the internal surfaces of these sides. Probably the most effective design is that resembling the bark of a tree. The collapsible sides are necessary to permit of the removal of the brick after the plunger has impressed the pattern on one or more faces as it consolidates the clay. The appearance of a wall is made more effective if bricks of several selected textures are built at random during its construction.

Rough sand-faced bricks, when wire-cut, are made by sprinkling sand (specially selected) through a sanding machine on to the clay band as it is being extruded. The sand is then pressed in by top and side rollers.

Pressed sand-faced bricks are made by sanding the internal faces of the mould before being charged. Hand-made bricks are sand-faced during the normal process (see p. 4).

DEFECTS IN BRICKS

The following are the principal defects to which bricks are subjected :—

Black Core or Hearting.—This is fairly common in bricks made of red clays (p. 1) which have been heated too rapidly in the kiln, causing the surface to vitrify and the interior to remain black.

Bloating or Swelling.—This is attributed to the presence in the clay of an excess of carbonaceous matter and to bad burning.

Burring or Clinkering.—Clamp-burnt bricks, usually adjacent to the flues, which have been fused together by excessive heat are called *burrs* or *clinkers*. Such are only suitable for breaking up for coarse aggregate (see p. 28).

Chuffs or Shuffs.—These are badly cracked and mis-shapen bricks produced by rain falling on them when hot. They are useless.

Crazing is a defect common in glazed bricks (see p. 16) characterized by fine cracks. These are due to the glaze and the body (clay) not expanding and shrinking to the same extent.

Crozzling.—Excessive heating in the kiln may produce mis-shapen bricks known as *crozzles*. If not too badly shaped they may be used for brickwork below ground level, otherwise they are only suitable for aggregates.

Efflorescence.—Bricks made from clay containing a relatively large proportion of soluble salts, particularly calcium sulphate, are liable to become discoloured by the formation of a whitish deposit. Whilst this efflorescence or *salting* is particularly common to new brickwork, it may also form on the faces of old external walls which are subjected to excessive dampness. It is formed as follows : The salts are dissolved when water is absorbed, and as the bricks become dry the salt solution is brought to the surface by capillarity, evaporation takes place and the salts remain on the face. In mild cases the efflorescence gradually disappears as the brickwork is subjected to alternate wet and dry periods, the rain removing the deposit until the salts are gradually eliminated. If the bricks contain a high percentage of salts the efflorescence may persist over a long period, and where dampness is caused from defective rain-water pipes or the omission of a damp proof course, the unsightly appearance may continue until the defect or omission has been remedied. Crystallization of the

salts may not occur on the outer surface of the bricks during evaporation but may take place just below the surface. This is called *crypto-florescence* and may result in the bursting off of the outer skin.

Portland cement mortar and certain lime mortars may cause efflorescence and affect the brickwork ; soluble salts present in the soil, such as chlorides and nitrates, may also produce this condition when the ground water is absorbed.

Grizzling.—Common bricks, though of good shape, which are underburnt (indicated by a light colour and a dull sound when struck), and therefore weak, are called *grizzles* ; only suitable for inferior internal partition walls when little strength is required.

Iron Spots.—These are surface dark spots, due to the presence of iron sulphide in the clay, which render the bricks unsuitable for facings.

Laminations are generally caused by the air in the voids between the particles of clay not being eliminated in the grinding, pugging, etc., processes, and producing the formation of thin laminæ on the faces of bricks which may scale off on exposure to the weather (see " de-airing," p. 3).

Lime Nodules.—Bricks containing pieces of limestone left uncrushed in the clay during its preparation are quite unsuited for external walls or internal walls which are to be plastered, as the lime will expand when water is absorbed, causing cracking or disintegration (see p. 1).

Scumming or Kiln-white.—This is an unsightly discoloration of bricks, particularly those containing lime and iron sulphide, which have been fired in a continuous kiln. Several causes contribute to this condition, but it is chiefly due to the hot gases from the firing chambers (which contain sulphur) coming in contact with the damp bricks in the early drying chambers, and producing a thin brownish-white or grey film (usually sulphate of lime) on the surface. Such bricks are only suitable for commons. Scum is prevented if provision is made for the escape of steam in the drying zone of the kiln (p. 7) and if clean hot air is only used to dry the bricks. Barium carbonate powder or barium hydroxide is sometimes mixed with the clay before moulding to prevent scum formation. The carbonate in a fine powder form may be added to the clay before it enters the auger or pug mill, or, as is usual, it may be mixed with water and the solution thoroughly incorporated with the clay.

Distortion may be produced by overburning. Badly worn auger mouth-pieces and press moulds will cause the bricks to be badly shaped. Cracking may be caused by drying and cooling the bricks too quickly in the kiln. Careless handling of green bricks during manufacture will cause damage. Chipped, cracked and broken bricks, especially if underburnt, are common results of improper handling in course of transit.

Terms which are gradually falling into disuse include *place bricks* (similar to grizzles, see above) and *shippers* (sound but imperfectly shaped bricks used as ships' ballast).

CHARACTERISTICS OF BRICKS

These have been referred to in Vol. I, p. 2. Good bricks should be thoroughly burnt, as most well-burnt bricks are durable and capable of withstanding relatively heavy loads. As adequate firing in the kiln tends to eliminate any soluble salts in bricks, it follows that hard-fired bricks are relatively free from defects such as efflorescence and crypto-florescence (see p. 13). Conversely, underburnt bricks (usually denoted by an abnormal light colour and a dull sound when struck together) are comparatively soft, easily broken, are neither durable nor pressure-resistant (see p. 15), and are liable to defects produced by salts.

Good bricks should be free from the defects enumerated above and, if used as facings, should conform to one or other of the colours and textures mentioned on pp. 12 and 13.

PERMEABILITY.—Bricks for external use must be capable of preventing rain-water from passing through them to the inside of walls of reasonable thickness. In this connection the practice of specifying the maximum amount of water a brick shall absorb (usually " one-seventh of its own weight of water after twenty-four hours' immersion ") is not now considered desirable, for it does not follow that a brick is impermeable if it has a relatively small absorption. Much depends upon the character of the pores.

Some pores are continuous from face to face, and therefore rain-water readily passes through them to the inside, whilst other pores or cavities are not interconnected but are entirely enclosed by material, and do not affect permeability. A close-pored brick will freely absorb water which will not readily evaporate. But a brick which is more open-pored will absorb less moisture, which will evaporate more easily because of the increased air circulation ; it follows that such a brick (provided any connected pores are not too large as to allow the water to be blown through them) is more successful in preventing dampness on the inside.[1]

Further, it is difficult to lay certain dense and smooth-faced bricks owing to their lack of " suction," which prevents a ready adherence of the mortar. This lack of adhesion causes narrow fissures to appear between the bricks and the mortar joints. The result is that water penetrates through these cracks, and much dampness in solid brick walls is due to this cause, even though the bricks may be impermeable (see p. 43). Hence, bricks should be porous to a certain extent, the pores being neither too fine nor too open, to permit strong adhesion of the mortar. Incidentally, even if the joints are well filled with mortar, especially if it is a rich mix (see p. 25), fine hair-like cracks may develop, when the mortar shrinks on drying, through which water will readily pass to the inside.

Permeability Test.—A simple apparatus used for measuring the rate of absorption of water consists of a flat pyramidally shaped brass cover which is fitted over the brick (or other) specimen, which is usually 4-in. square ; a short length of vertical glass tubing, with its lower end fixed to the cover, is fitted to a fine bored glass tube (having a scale behind it) which is fixed horizontally at 8-in. above the top surface of the specimen ; a rubber pipe from a glass cylinder containing water is connected to the vertical tube ; the vertical faces of the specimen are waxed and thus made

[1] Briefly the distinction between absorption, permeability and porosity is as follows :—
Absorption is the property of allowing water to enter a material.
Permeability is the property of allowing water to pass through a material.
Porosity is the proportion of void space in a material.

impermeable. Water from the cylinder is admitted to occupy the space between the top of the specimen and the under side of the cover and to fill both vertical and horizontal tubes ; the water is then shut off. As the water passes through the specimen, it flows along the horizontal tube ; this rate of flow is obtained by observing the end (or meniscus) of the water and measuring from the scale the distance this travels in a given time. The 8-in. head of water gives a pressure in excess of that caused by a very strong force of wind against a wall down which rain is pouring (see also p. 99).

STRENGTH.—It is not necessary to specify the strength of bricks unless they are required for the construction of piers, etc., which have to support heavy concentrated loads. The reason for this is that the compressive strength of brickwork constructed of relatively inferior bricks will be quite adequate to resist the normal weight which it will be required to support. Thus, whilst the brickwork at the ground level of a two-storied house will not usually be subjected to a greater load than 1¼-tons per sq. ft., it would be a very poor brick which had a crushing strength of less than 60-tons per sq. ft. The average crushing strength of bricks serves as an approximate index only of the compressive strength of brickwork, as much depends upon workmanship, height in relation to thickness, etc. A rough approximation of the strength of brickwork built in cement mortar (1 : 3) and good hydraulic lime mortar (1 : 3) is respectively one-third and one-fifth that of the individual bricks.

The crushing strength of bricks is determined in a compression machine such as that shown at E, Fig. 9 (see p. 32). A brick is usually tested on bed and placed in the machine between two pieces of plywood, any frogs being filled flush with cement mortar. The compressive strength varies enormously between batches from the same kiln and even of individual bricks from the same burning. As an illustration of this, tests carried out in the Building Laboratory of the Manchester College of Technology on six bricks obtained from a kiln at the same time showed the crushing strength to vary between 1,450 and 2,410-lb. per sq. in. This variation is partly due to the different position of the bricks in the kiln. It is because of this variation that at least six (preferably twelve) specimens of a brick should be tested and the mean figure taken.

This variation is also shown by the following figures in brackets which indicate the approximate crushing strengths of specimen wire-cut, pressed and hand-made bricks (six of each type) from well known and reputable manufacturers: Wire-cut commons and facings (1,800 to 5,000-lb. per sq. in.), pressed commons and facings (2,500 to 6,000-lb. per sq. in.) and hand-made facings (2,000 to 5,000-lb. per sq. in.). Engineering bricks (see p. 17) have crushing strengths varying from 8,000 to 18,000-lb. per sq. in.

FROST ACTION.—External walls constructed of porous underburnt bricks are particularly vulnerable to damage by the action of frost. Such damage is due to the absorbed water expanding (to about one-eleventh of its volume) as it freezes and exerting pressure on the pore walls which the comparatively soft material is unable to resist. Disintegration thus results, and when this is repeated during severe winters, disfigurement due to pitting and cracking of the surface and damaged arrises may become very pronounced. Brickwork of poor quality bricks with overhand struck joints (see p. 31, Vol. I), that below the ground level, and copings are particularly subject to damage by frost. It does not affect brickwork of sound, hard-burnt bricks.

Frost Resistance Test.—A simple, but effective, apparatus in which bricks and other building materials may be tested for frost resistance is shown in Fig. 35 and described on p. 100. This test can also be carried out in a watertight metal container which is partly filled with a freezing mixture consisting of 2 parts ice and 1 part common salt. The brick to be tested, after being immersed in water for twenty-four hours, is wrapped in a piece of cloth, totally immersed in the mixture, the lid is shut and the container is placed in a box so that it is encased by a 3-in. thickness of cork, sawdust or similar insulating material. After being frozen at − 10° C. for eighteen hours the specimen is removed, thawed by running water, unwrapped and examined. The freezing and thawing cycle is repeated for at least ten times. Certain bricks, well known for their durable qualities, are not affected even if subjected to forty freezings, whilst others, only suitable for internal work, will show serious disintegration after ten freezings. This apparatus does not give such good results as that illustrated in Fig. 35, as the immersion of the specimens in the freezing mixture appears to improve their resistance to frost action on account of their impregnation with salt.

A good test, but one which does not give immediate results, consists of digging a hole and placing in it two bricks on end, one above the other, with the upper brick half exposed. These are left for a year. In a normal winter successive frosts will cause a poor brick to crack across at ground level, whilst the lower one may show signs of flaking. Sound bricks will not be affected.

Efflorescence Test.—A brick is partially immersed on end in a dish of distilled water, and the water absorbed is evaporated from its upper surfaces. Any salts liable to form efflorescence are brought to the surface by the water in its passage through the brick.

CLASSIFICATION OF BRICKS

Bricks may be classified according to (1) quality and (2) usage.

1. CLASSIFICATION ACCORDING TO QUALITY.—Bricks from a kiln are divided into three classes, namely : (*a*) *firsts*, which are best and are selected by hand ; (*b*) *seconds*, which are selected bricks but are not equal to " firsts " on account of some imperfection in regard to colour or shape or both ; (*c*) *thirds*, which are the remainder of the kiln, the best being only suitable for interior work.

2. CLASSIFICATION ACCORDING TO USAGE.—A conveniently broad division of bricks is in accordance with their suitability for (*a*) interior purposes, (*b*) exterior purposes, (*c*) pressure-resisting purposes and (*d*) fire-resisting purposes.

(a) *Bricks for Interior Purposes.*—Common bricks are invariably specified for internal walls, as neither strength, durability nor appearance are important.

If the walls are to be plastered it is essential (especially if the bricks have a large suction capacity) that the walls shall be copiously watered before the first coat is applied, otherwise an excessive amount of water will be absorbed from the plaster and this may cause failure. It is also important that the bricks shall not contain nodules of lime (see pp. 1 and 14), as the water applied to walls prior to plastering will be absorbed, causing the lime to slake and the resultant expansion to crack or splinter the bricks.

It is essential that certain brick partitition walls, particularly those on upper floors, shall be as light as possible, and perforated or hollow bricks or blocks (see U, V, W and Y, Fig. 5) are suitable for this purpose.

Sometimes facing bricks, and not commons, are required for internal walls, such as those for churches, corridors, class-rooms, etc. Light-coloured bricks, such as " silver-greys " (p. 12) and sand-lime bricks (p. 17) are used for such purposes on account of their satisfactory light-reflecting qualities. White, etc.,

glazed bricks (see next column) are also used for internal walls of dairies, factories, lavatories, etc.

(b) *Bricks for Exterior Purposes.*—The essential requirements of facing bricks are durability, colour, texture and freedom from defects. Colour and texture are not important if the walls are to be rough-casted or plastered, good quality commons being sufficient for this purpose. They should have sufficient suction capacity to ensure the thorough adhesion of the mortar (see p. 14). The crushing strength is not material unless heavy loads have to be supported, as any durable brick will safely support the load which has to be normally resisted. Bricks to be used below the horizontal damp proof course should be carefully selected, as these are subjected to the greatest frost action (p. 15), and absorption of certain salts from the soil may cause deterioration if the bricks are not durable.

(c) *Bricks for Pressure-resisting Purposes.*—These are required for the construction of piers, large-spanned arches, etc., where large stresses have to be resisted. Strength is therefore the chief requirement, and engineering bricks (p. 17) which are very strong and hard burnt are most suited for this purpose.

(d) *Bricks for Fire-resisting Purposes.*—Those best suited to resist high temperatures, as for lining furnaces, chimney stacks, boilers, etc., are fireclay, silica, ganister, bauxite and magnesite bricks (see below).

The following is a summary of several types of bricks which have not been already described :—

FIREBRICKS.—These are capable of resisting very high temperatures and are used for lining fireplaces, tall chimneys, furnaces, gas retorts, etc. They are made from (*a*) fireclay, (*b*) silica rocks and (*c*) silica rocks together with *ganister*.

(a) *Fireclay Bricks.*—Fireclays or refractory clays are associated with coalfields, and are usually obtained by mining as distinct from quarrying. They are found in many parts of this country. The clay contains from 55 to 75 per cent. silica and 22 to 35 per cent. alumina.

The fireclay is crushed and finely ground. Grog (finely ground burnt fireclay) is often mixed with the material to reduce shrinkage. The mixture is then soured to increase its workability (p. 4), moulded (pressed), dried and hard burnt for about seven days. The maximum temperature for firing first-class bricks should not be less than 1,500° C. The bricks are of a cream or buff colour.

(b) *Silica Bricks.*—These contain 95 to 97 per cent. of silica and 1 to 2 per cent. lime. The rock is crushed by heavy rollers, then ground in a pan mill in which the lime is added in correct proportion and in liquid form ; the lime acts as a binding material. Powerful presses are used to mould the bricks and the burning takes place in kilns of either the down-draught, chamber (similar to the zigzag) or tunnel type. Good silica bricks should resist a minimum temperature of 1,300° C. They are very brittle. Well-known silica bricks are produced in South Wales (from the Dinas rock, quarried near Swansea) and they are particularly suited for the lining of metallurgical furnaces and coke ovens.

(c) *Ganister Bricks.*—Ganister is a dark-coloured sandstone containing up to 10 per cent. of clay. It is quarried in this country (Sheffield being an important centre), Wales and Scotland. Their manufacture is similar to that of silica bricks. They are very refractory, as they are capable of withstanding a temperature of 1,800° C., and are therefore particularly suited for lining furnaces, etc.

BAUXITE BRICKS (made from an aluminous earth imported from France), MAGNESITE BRICKS and CHROMITE BRICKS (both also made from imported material) are other highly refractory products. They are used for lining special furnaces, such as steel and blast furnaces and cement kilns, and are generally gas-fired.

RUBBERS OR CUTTERS are soft red (chiefly), white or buff coloured bricks, consisting of washed loamy clay containing a large proportion of sand, and are usually hand-made in a box-mould (p. 4) and baked (not burnt) in a kiln. The colour is uniform throughout, and owing to their softness and fine-grained texture they are easily cut, rubbed and carved. They are used principally for gauged arches, decorated quoins and jambs.

GLAZED BRICKS.—Fireclays or shales are best for producing glazed bricks. As they are usually required to be built with joints not exceeding $\frac{1}{8}$-in. thick, they must be true to shape, with fine straight arrises. They are therefore carefully pressed and sometimes re-pressed, with the arrises hand-trimmed with a strike. Glazed bricks are impervious and are of two kinds, namely : (1) salt-glazed and (2) enamelled.

1. *Salt-glazed Bricks* are usually produced in a down-draught kiln.[1] Salt is thrown on to the fires of the kiln after the bricks have reached a temperature of about 1,200° C. The heat vaporizes the salt and causes it to combine with the clay to form a vitreous or glassy surface which cannot scale off. Usually two, and not more than three, charges of salt are applied at about twenty-minute intervals when the bricks have reached the required temperature, a shovelful of salt being thrown on to each fire. The colour of the glazed surfaces is a brown of various shades. Such bricks are used for internal dadoes, lavatories, basements, areas, large brick sewers, inspection chambers, etc.

2. *Enamelled Bricks.*—These are now obtainable in a large variety of colours. There are two methods of producing these, namely : (*a*) dry-dipped and (*b*) wet-dipped.

(a) *Dry-dipped Process.*—These enamelled bricks are called *biscuit-ware*. They are moulded, dried, burnt to a temperature of approximately 1,200° C. (this is called *biscuit-burning*), cooled, prepared for glazing, coloured, glazed and re-burnt. The colouring, glazing and preparation (called *bodying*) are done on a bench in a shed. At least three vessels containing liquid or *slurry* of varying consistency are placed on the bench. The first vessel contains the *slip* or *engobe* or *body*, and is a mixture of china clay (which is slightly plastic and found in Cornwall, Devon and Dorset), crushed burnt flints, ball clay (more plastic than china clay), etc., and water. The second tub contains a similar mixture with the addition of metallic oxides (such as those stated on p. 12) to give the required colour. The liquid in the third vessel is called the *glaze*, and this is a mixture of china clay, felspar (a silicate of alumina with varying proportions of sodium, potassium, etc.), whiting and water. The proportions of the ingredients vary considerably. More than one tub containing colouring bodies are sometimes required to give the desired colour, the ingredients and proportions being determined as a result of experience and exhaustive tests. The bricks are first washed, one stretcher or one header face (or both) being hand-brushed with water. Each brick is then separately treated, the washed face(s) being hand-dipped into the slip, then into the colouring solution and finally into the glaze. After the edges have been trimmed with a wire brush to remove the surplus glaze, the bricks are very carefully stacked in the kiln and burnt to fuse the glaze. Thus, these bricks are subjected to two separate burnings. Coal and gas are the fuels used, gas kilns being most successful for this class of bricks.

(b) *Wet-dipped Process.*—The slip, colouring solution and glaze are applied direct to the bricks immediately after they have been moulded and dried. They are afterwards very carefully burnt. Whilst this is a cheaper method than (*a*), only one burning being required, the results are not so good and there is a large proportion damaged during the handling operations. Such bricks are only suitable for inferior work.

Glazed bricks, especially biscuit-ware, are used for first-class faced work as required for factories, dairies, certain shops, abattoirs, corridors, dadoes of classrooms, lavatories, areas, wells of large buildings, external facings, etc. The surfaces can readily be washed down, and white glazed bricks are particularly effective in areas of buildings and in places where the maximum reflected light is required.

PERFORATED BRICKS.—Perforated bricks, such as is shown at U, Fig. 5, are made by the wire-cut process (p. 3), the small holes of varying diameter ($\frac{3}{8}$ to $\frac{5}{8}$-in.) being formed as the clay column is extruded through the mouthpiece in which short horizontal bars are fixed. The advantages claimed for these bricks are : A saving

[1] Tunnel kilns are also used for this purpose.

in clay results, the drying and burning processes are facilitated, resulting in a reduction of fuel, they are light to handle (the perforations reducing the weight by about one-fifth) and because of this comparative lightness the cost of carriage is reduced. Several forms of perforated bricks are used in *reinforced brickwork* (see p. 45). Additional mortar may be required for the bed joints, especially if the holes are large.

AIR BRICKS.—If of standard size, the green bricks are machine-made in the usual manner (pressed or wire-cut), otherwise they are hand-made in a box-mould (p. 4). Each slab is then perforated thus: A templet of thin zinc, the size and shape of the bed and perforated as required, is placed on top of the slab (which usually has an oiled surface) laid on bed, fine sand is dusted over it, the templet is removed, leaving a light-coloured pattern of sandy squares on the surface. These serve as a guide for the moulder who takes a hollow steel tool, square in section and having sharp cutting edges, and presses it through the slab at each square of the pattern. The tool is withdrawn, and the clay within is removed by passing a solid metal rod down it. The section is similar to U, Fig. 32, Vol. I. Cheaper air bricks, having thin perforated panels, are stamped by a press.

HOLLOW, CELLULAR OR CAVITY BRICKS (see V and W, Fig. 5).—The cellular type has ¾ to 1-in. thick "walls" or "skins" with two or more "webs" or "diaphragms." They are light and are therefore suitable for partitions; their cavities also reduce the transmission of sound and heat. They are machine pressed, the plunger, having solid metal cores, forming the cavities as they descend. These bricks are sometimes glazed and are often made of fireclay.

HOLLOW BLOCKS (see Y, Fig. 5).—These are used in the construction of partitions. Somewhat similar blocks are employed in the construction of fire-resisting floors.[1]

They are usually made of fireclays or shales by the wire-cut process (p. 3). The shape of the blocks depends upon the special provision made in the mouthpiece of the auger, and there are several patent devices for forming the hollows. One of the simplest consists of a strong thin metal frame which projects into the die from the front and two solid horizontal metal cores or bars which are secured to it. As the clay is pushed through the die, the cores produce two voids in the extruded column. At the same time any grooves in the sides are formed by projecting ribs on the sides of the die. The extruded column is passed to the cutting table, the frame being pivoted to cause the wires to cut it into the required lengths by a downward movement.

Some hollow blocks are solid-ended. One device fixed in the die to produce such blocks consists of a square shutter (the size of the cross-section of the void) which is fitted to the top and caused to descend and rise automatically at required intervals. When the shutter is down it occupies a central position in the die, and this produces the hollow portion of the column as it proceeds. When the shutter rises clear of the die, the section of the moving clay band is solid. Thus a column is produced which is hollow, having solid partitions at intervals, the thickness of the latter being equal to twice the finished thickness of an end. The column is then cut at the table, the wires being drawn centrally down through these solid portions. Drying and burning complete the process.

PAVINGS are very hard-wearing bricks used, as implied, for paving roads and paths. They are sometimes salt-glazed, each with one face roughened or chequered to increase the foothold. They are laid on edge on a concrete bed with a ½-in. bed joint of cement and sand (1 : 2) and the vertical joints, ½-in. thick, are grouted with cement and sand (1 : 1½). These bricks are now very rarely used.

ENGINEERING BRICKS.—These are exceptionally strong and durable, and are used for piers, bridges, sewers and similar engineering purposes. Those most noteworthy are Accringtons (pressed), Southwaters (pressed and wire-cuts), blue Staffordshires (wire-cuts and hand-made) and Hunzikers (made of crushed flint and lime).

SAND-LIME BRICKS.—These are of the same size as ordinary clay bricks and are made of a mixture of sand, lime and water which is pressed into moulds and hardened. Their colour is grey or a dull white, although oxide pigments may be added to give other colours. The sand should be clean and well graded, and the normal proportion used varies from 92 to 95 per cent. of the dry mix. The 5 to 8 per cent. of lime which is mixed with the sand may be of any class, provided it can be thoroughly well slaked. It must be properly burnt (see p. 19) as overburnt lime does not readily slake and underburnt lime has a high calcium carbonate content which is valueless. The slaking or hydration must be complete before the mixture is pressed.

There are three stages in their production, namely: (*a*) mixing, (*b*) pressing and (*c*) hardening.

(a) *Mixing.*—The burnt lime (quicklime) is finely ground in a ball mill (p. 22) and passed through a sieve to eliminate coarse-grained particles. This is mixed with sand in the correct proportion in an edge-runner (p. 2) and slightly more than the required amount of water added to slake the lime. The mixture is passed to a hopper or silo and left for a variable period (generally twenty-four hours) to ensure thorough hydration.

(b) *Pressing.*—The rotary table type of press (p. 3) is generally used, a measured quantity of the material being fed, pressed into a slab and removed. The pressure varies with the water content and must be sufficient to enable the bricks to be handled without damage.

(c) *Hardening or Autoclaving.*—A "kiln" in which the bricks are hardened is a 5½ to 7-ft. diameter steel cylinder, varying from 30 to 70-ft. long, and is called an *autoclave*. The pressed bricks are stacked on cars (similar to those used in tunnel kilns, see p. 10), each truck taking up to 1,500 bricks. The loaded cars are run into the autoclave, the tight-fitting doors are closed, steam is admitted and the pressure gradually increased. The maximum steam pressure varies with the length of time at which it is steadily maintained, the greater the pressure the shorter the time of autoclaving; thus, if a steady pressure of 120-lb. per sq. in. is applied, the period varies from eight to twelve hours, whilst this time may be halved if the pressure is increased to 200-lb. per sq. in. After steaming for the required period the supply of steam is shut off and the bricks allowed to cool by opening a valve. The loaded cars are then removed.

Sand-lime bricks are of uniform colour, texture, size and shape, with sharp square arrises. Their fine texture renders them suitable for carving, and figures carved *in situ* on the brickwork have successfully relieved the somewhat monotonous appearance of large uniformly coloured surfaces.

Although these bricks have not been subjected to prolonged tests, it is considered that those of best quality compare favourably with good quality common bricks as regards compression strength and durability. They are only moderately resistant to frost action and are therefore not suitable for brickwork below ground in water-logged sites. They have been used successfully as a cheap substitute for white glazed bricks in wells of buildings and similar positions where maximum light is required.

CEMENT AND CONCRETE BRICKS.—Portland cement is used to a relatively small extent in the making of bricks. Sand as a fine aggregate is added to the cement in varying proportions, suitable mixes being 1 part cement to 6 or 8 parts graded sand. The materials are well mixed in a machine, just sufficient water being added to ensure adhesion. The mixture is then pressed in moulds or in a rotary table machine, removed and dried slowly for at least a fortnight (preferably a month) before being used. The bricks are covered with damp cloths during the maturing period. Rapid-hardening cement (p. 24) in lieu of ordinary Portland cement expedites the setting period.

CONCRETE BLOCKS of various sizes and mixes are also made, the aggregates being sand, broken brick, broken stone, gravel, coke breeze, etc. (see p. 28).

Cement and concrete bricks or blocks have not become popular in this country, chiefly on account of their dull, uninteresting appearance, although concrete slabs are often employed in the construction of internal partitions, (p. 45, Vol. III).

BREEZE SLABS of various sizes (usually 2 to 2½-in. thick) and consisting of 1 part cement to 6 or 8 parts powdered breeze have been extensively used for partitions in positions where loads have not to be supported (p. 15). These are cast in wood moulds. Cavity walls (p. 40) are sometimes constructed of breeze slabs which are approximately 3-ft. by 1-ft. by 2½-in. thick, placed on edge between reinforced concrete pillars.

SPECIAL SHAPED BRICKS.—A selection of special shaped bricks, most of which are standard, is shown in Fig. 5. They are kept in stock by the larger brick

[1] Detailed in Vol. IV.

manufacturers, and are chiefly made by machinery (pressed or wire-cut). This results in a reduction in cost, as non-standard bricks can only be purposely made by hand in moulds which have to be constructed to the specified requirements. The increased availability of standard specials has also resulted in a saving of time of the bricklayer which was formerly occupied in cutting the bricks to shape.

Squint Bricks (see A, B, C and D, Fig. 5).—These are used in the construction of acute and obtuse squint quoins (see p. 36).

Bullnose Bricks.—A double bullnose brick is shown at Q, Fig. 2, Vol. I. It is difficult to cut neatly a mitre at the intersection between two bullnose arrises ; special *returns* containing mitres are therefore useful. That at E (opposite) shows an internal return ; similar right and left handed returns on bed, edge and end are also available. An external return is shown at F. A *stop* is required to provide a satisfactory finish when a bullnose edge is continued by a square arris, as at the base of a pier or jamb ; a double stop is shown at G ; single stops are also made. That shown at H, sometimes called a *cownose*, is suitable for copings and jambs of 4½-in. walls.

Dog-leg or Angle Bricks (see J).—These are also used at squint quoins, particularly of cavity walls (see E, Fig. 11).

Birdsmouth Bricks (see K, Fig. 5).—These may be used at alternate courses of internal squint quoins or for decorated serrated courses.

Circular Bricks (see stretcher L and header M).—These are used for circular work as in the construction of bay windows (see Figs. 15 and 27), apsed ends, staircase wells and tall chimneys. These are referred to on p. 44.

Coping Bricks.—A few standard shapes are shown at N, O and P. Bullnose bricks are used for the same purpose.

Pistol Bricks (see Q).—These are used for forming circular or coved angles between walls or between a wall and a floor.

Plinth Bricks.—These are referred to on p. 29, Vol I. A dogleg internal angle plinth is shown at R (opposite) and a stop is shown at S. Right and left handed plinth internal returns, like the bullnose brick E, and external angles are also obtainable from stock.

Keyed or Nicked Bricks.—The type shown at T, manufactured by the London Brick Co. Ltd., has dovetailed grooves formed on one stretcher and one header face for the purpose of providing a mechanical bond with either plaster or roughcast which may be applied to the brickwork. They are obtainable as commons, as shown, or as cellulars (see V).

Perforated Bricks (see U).—These have small holes (⅜ to ⅝-in. in diameter) formed throughout their thickness, the object of which is to reduce their weight (pp. 15 and 16).

Hollow Bricks.—These are made of clay formed with one or more cavities which reduce their weight some 25 per cent. and increase insulation against heat, sound and moisture (see p. 17). The cellular type V, made by the above firm, has three cells separated by tapered webs ; these cells are open to one bed and extend to within about ¼-in. from that opposite. The " Webcel,"

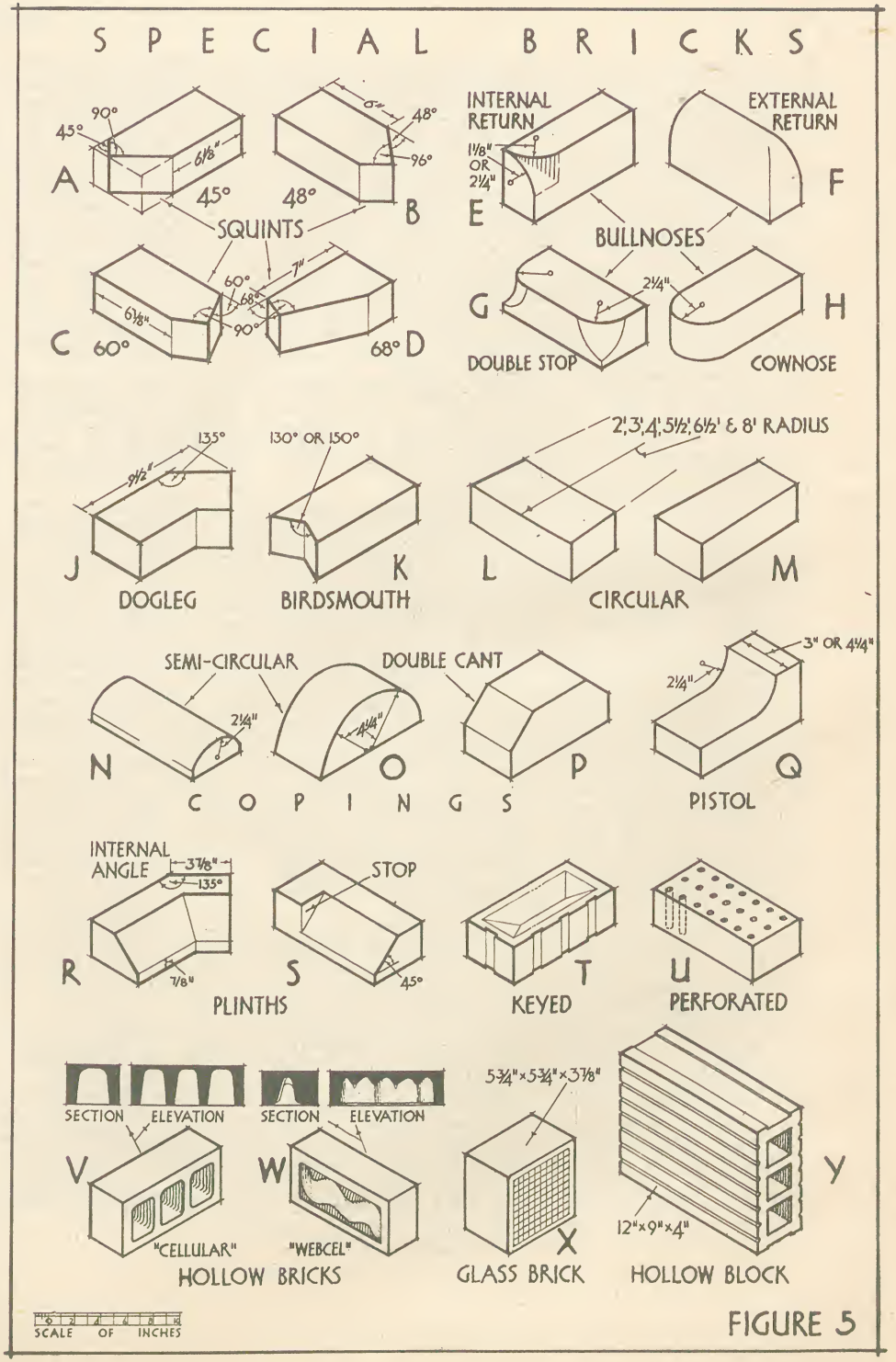


FIGURE 5

type W, manufactured by the Marston Valley Brick Co. Ltd., has a single void, shaped as shown. These bricks are laid with their solid beds uppermost and are particularly effective in the construction of partition walls.

HOLLOW BLOCKS.—One of several types of walling blocks is shown at Y. The thickness varies from 1½ to 9-in. Some have only two cells, whilst another type having a central web has ten cells. They are used for partitions ; the fluted sides and beds provide a good key for the plaster, and the cells reduce the transmission of sound and heat, besides decreasing their weight (p. 17).

GLASS BRICKS (see X).—There are two types, *i.e.*, solid cast blocks of glass and hollow glass blocks, the latter being made in two halves before being joined and hermetically sealed. They are not capable of resisting heavy loads, but they can be built into panels to any practical height, and are being used to form semi-transparent walls and partitions to steel framed buildings, etc. (see p. 48, Vol. III). The bricks are bedded and jointed with lime mortar like clay bricks ; they are not usually bonded, the vertical joints being continuous. The mortar recommended consists of 1 part lime, 1 part Portland cement and 4 parts sand. Panels exceeding 6-ft. in width should be reinforced with hoop iron or expanded metal (see p. 45) at every third to fifth course ; vertical rod reinforcement is necessary if the panels exceed 20-ft. in width. Provision must also be made for expansion at the sides and tops of panels. The bricks are made in various sizes and patterns, the largest size being 7¾-in. by 7¾-in. by 3⅞-in. (See p. 48 and Fig. 13, Vol. III)

LIME

MANUFACTURE.—Lime is produced by burning chalk or limestone in a kiln. There are two types of kiln, *i.e.*, (1) intermittent and (2) continuous.

(1.) *Intermittent Kiln.*—This is the simplest form of kiln and is one which is in use in many parts of the country. That shown in Fig. 6 is one of several kilns in which lime used extensively in the North of England is produced. The kiln is situated at the side of a cutting (often the face of the quarry) ; the four walls are tapered and are lined with firebrick ; it is open at the top. A loosely built rough arch of pieces of the unburnt limestone is formed at the bottom, and this supports alternate 18-in. thick layers of limestone and 9-in. thick layers of fuel (1 to 1½-in. coke nuts). Both the limestone and coke are charged into the kiln from side-tipping tubs which operate on a track on each side and at the top of the kiln. A coal fire is started in the fireplace below the arch and it gradually extends to the layers of fuel and limestone until the whole mass is brought to a bright red heat (900° C.). The period of burning is about four days. The burnt lime is then removed through the *eyes*, after which the kiln is again charged. The cover provided by the arched portion at the front of the kiln affords an adequate protection to the freshly burnt lime as it is withdrawn, and the top is generally protected by an open roof. The capacity of this kiln is about 20-tons of limestone and 8-tons of coke.

Lime produced in this manner is used for mortar.

Sometimes this form of kiln is charged wholly with pieces of limestone, and the fire is maintained at the bottom for a few days until the whole of the limestone or chalk has been thoroughly burnt. This is commonly known as a *flare kiln* and produces a white lime, free from discoloration and especially suitable for plastering.

2. *Continuous Kiln.*—The simplest form of continuous kiln is the *draw* or *tunnel kiln*. This is a brick structure, firebrick lined, in the form of an inverted truncated cone, about 16-ft. high, 8-ft. diameter at the top and 4-ft. diameter at the base, having a fireplace with grating at the bottom. It is charged with alternate layers of limestone and coal or coke. The process is continuous, the burnt lime being withdrawn at the base, and raw limestone and fuel added at the top. Some tunnel kilns have the lower half below ground, from the draw hole at the base of which is an inclined shaft or tunnel. Such are known as *sunk draw* or *tunnel kilns*.

Another form of continuous kiln consists of a steel cylindrical shaft, firebrick lined, some 50-ft. high and 8-ft. diameter, with several furnaces at the base, and so designed that only the hot gases come into contact with the limestone. Such kilns are economical in fuel consumption, and the lime which is withdrawn at suitable intervals is free from discoloration.

The Hoffman kiln, described on p. 10, is another form of continuous kiln used for burning lime and is suitable for the production of large supplies. The following is a brief description of such a kiln which has been in continuous use for the past seventy years.[1]

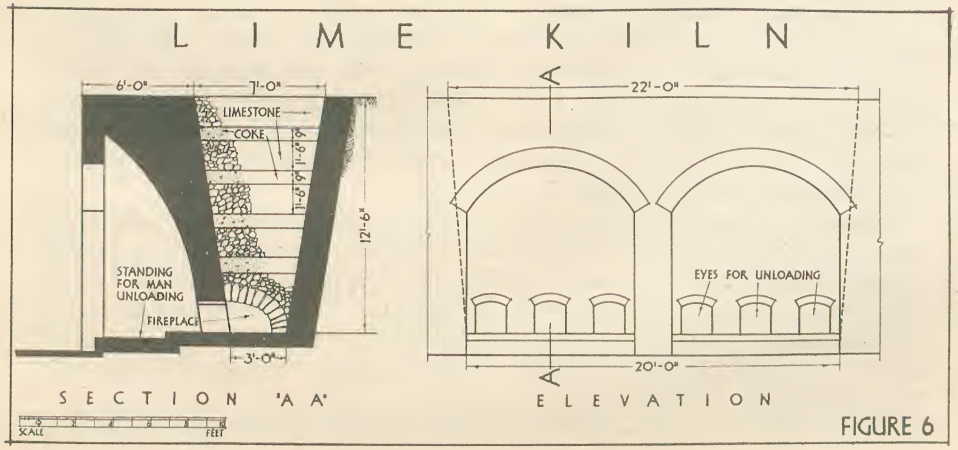


FIGURE 6

It has twenty-eight firebrick lined chambers, each having a wicket and a damper controlled flue which is connected to the main horizontal flue leading to a central chimney stack. The kiln has no permanent partitions.

Two sections of the kiln, each of ten chambers, are drying, burning and cooling at the same time, and there is a gap of four chambers between each section to permit of stacking, unloading and the carrying out of repairs. A party of men is constantly

[1] At the Buxton Limeworks of Messrs Imperial Chemical Industries Ltd.

removing the cool burnt lime from the front of each section, whilst another gang is stacking the limestone at the back of each section. Like the brick kiln of this type, the sequence of operations is advanced by a chamber each day, and thus, as there are two sections, the equivalent to two chambers is being unloaded and two loaded daily. The limestone is stacked, with horizontal flues parallel to the length of the kiln formed at the base, and vertical flues formed under the feed-holes provided at the top. Coal slack is the fuel used, and this is fed to the lime which is being subjected to the maximum temperature. The wickets to the drying and burning chambers are sealed with half-brick thick walls daubed over with grouted lime, and the face of the last stacked chamber in each section is covered with brown paper to exclude draught from the open wickets in front. Lightly burnt lime suitable for building purposes (mortars and plasters) is obtained at normal temperatures of 1,100° to 1,200° C. in the firing chambers, but proximity to the flues and longer heating periods produce a proportion of more solidly burnt lime suitable for the preparation of caustic soda. Whilst unloading the burnt lime, it is hand-picked, selected and graded, the lightly burnt being white in colour and the hard-fired or overburnt being dark coloured.

Slaking, Setting and Hardening of Lime.—Pure limestone or chalk is composed of carbonate of lime ($CaCO_3$). When this is heated in a kiln it yields calcium oxide (CaO) or *quicklime* and carbon dioxide (CO_2) which is driven off.

When the quicklime is *slaked* by the addition of water heat is evolved, and the lime expands and falls to powder. If just sufficient water is added to accomplish this action, the powder is dry and is called *hydrated lime* (see p. 21). This slaked or hydrated lime is calcium hydroxide ($Ca(OH)_2$), the action of slaking being expressed by the equation $CaO + H_2O = Ca(OH)_2$. If more water is added to the slaked lime it does not chemically combine with the lime but reduces it to a paste known as *lime putty*.

On lime putty being exposed to the atmosphere, it begins to set and gradually hardens to form carbonate of lime as the water evaporates and carbon dioxide is absorbed from the air. *This is known as "carbonation," and is an important property, as the hardness of certain lime mortars is dependent upon it.* The chemical action which takes place on carbonation is represented by the equation $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$ (which is evaporated).

The slaking of hydraulic limes is referred to in the next column.

Classification.—The composition of various limestones differs considerably, and thus there are a number of different kinds of limes each having characteristic properties which influence the purposes for which they are used. This is one of several classifications[1] of lime: (1) Pure, Fat, White or Rich; (2) Lean, Poor, Grey Chalk or Stone; (3) Hydraulic or Blue Lias; and (4) Magnesian. The schedule at the top of next column shows an approximate analysis of a typical specimen of each of these varieties.

1. *Pure, Fat, White or Rich Lime* contains less than 5 per cent. of impurities such as silica and alumina (in the form of clay). In the analysis the specimen is shown consisting almost entirely of calcium oxide. It slakes rapidly, evolves much heat, and expands from two or three times its original bulk during the process, has a high degree of plasticity (hence the name "fat"), is slow setting and very slow in hardening. This stiffening up can only occur when the lime is in contact with the air (see preceding column). Whilst pure lime, which is white in colour, is extensively used for plastering, it is not so suitable for lime mortar on account of its slow-hardening characteristic and lack of strength (unless gauged with cement, see p. 27).

[1] The latest classification appears in the British Standard Specification for Building Limes, No. 890—1940, which divides quicklime into two classes, *i.e.*, Class A—Lime for plastering finishing coat, coarse stuff and building mortar, and Class B—Lime for coarse stuff and building mortar only. It gives particulars of several tests.

	Pure.	Lean.	Hydraulic.	Magnesian.
Calcium oxide (CaO)	93·0	82·0	67·0	57·22
Magnesium oxide (MgO)	0·4	0·6	1·0	38·38
Silica (SiO_2)	1·0	6·0	17·5	2·19
Alumina (Al_2O_3)	0·6	3·7	7·0	0·69
Iron oxide (Fe_2O_3)		1·7	2·5	0·68
Carbon dioxide, water, etc.	5·0	6·0	5·0	0·84
	100·0	100·0	100·0	100·00

2. *Lean, Poor, Grey Chalk or Stone Lime* contains more than 5 per cent. of clayey impurities and is therefore less pure than fat lime. In the above analysis the impurities of silica, alumina and iron oxide amount to over 11 per cent. The characteristics are somewhat similar to those of fat lime, but on account of its impurities it slakes less rapidly (resulting in a diminution of heat and volume) and its iron content is responsible for its grey colour. Like fat lime, it sets and hardens slowly. It is used for both plaster and lime mortar.

3. *Hydraulic or Blue Lias Lime.*—This class of lime is capable of setting and hardening when not in contact with air and even if submerged in water, hence the name. Hydraulic lime is therefore unlike both pure and lean limes which, as already stated, will only stiffen when the water is evaporated from the putty and carbonation takes place as the CO_2 is absorbed from the air.

Limestones from which hydraulic limes are prepared contain varying proportions of silica and alumina (in the form of clay), in addition to the calcium oxide (see analysis). The clay and iron oxide play an important part in the setting and hardening of such limes. Quicklime is formed when the carbon dioxide is driven off the calcium carbonate as the limestone is burnt in the kiln. This quicklime, having a strong affinity for the clay, combines with it to form silicates and aluminates of lime.

Slaking.—If water is added to this burnt product after it has been finely ground the mass begins to set and harden as the water combines with the various products. As this action is not dependent upon the presence of carbon dioxide, the hardening will continue even when air is absent. The setting and hardening are therefore similar to the behaviour of Portland cement, the composition of which it closely resembles—compare the above analysis of hydraulic lime with that of Portland cement on p. 23.

These limes have been subdivided into (*a*) feebly hydraulic, (*b*) moderately

hydraulic and (*c*) eminently hydraulic, according to the percentage of silica and alumina present.

(a) *Feebly Hydraulic Lime.*—This contains less than 15 per cent. of silica and alumina. The rate of slaking is slow (varying from five to sixty minutes) and the expansion on slaking is small. It produces a good mortar.

(b) *Moderately Hydraulic Lime.*—The silica and alumina content varies from 15 to 25 per cent. Slaking is very slow and the expansion is small. It makes an excellent mortar, is stronger than feebly hydraulic lime and is suitable for good-class brickwork and masonry.

(c) *Eminently or Very Hydraulic Lime.*—This contains from 25 to 30 per cent. of the important constituents of silica and alumina, and its chemical composition is very similar to that of ordinary Portland cement (see p. 23). It is also known as *blue Lias lime*, as it is found in the Lias formation which extends throughout part of Yorkshire and the Midlands. This lime is similar to, but stronger than, the moderately hydraulic variety. It must be very finely ground and must be screened before use to eliminate coarse unslaked particles. It closely resembles Portland cement (p. 22) and is used for similar purposes.

4. *Magnesian or Dolomitic Lime.*—The rocks from which such limes are produced are known as magnesian limestones or dolomites, as they contain up to 45 per cent. magnesium oxide.[1] The latter has similar characteristics to calcium oxide although it slakes much more slowly. This is an excellent lime and is generally used in the localities in which the magnesian limestones are found.

Air Slaking.—The burnt lime should be slaked as soon as possible after it arrives on the site, otherwise moisture and carbon dioxide from the atmosphere will, in course of time, reduce the lime to a powder, *i.e.*, it will become air slaked. This is undesirable, for, carbonation having taken place, the particles of carbonate of lime are incapable of setting, and thus adulterate any mortar with which they may be mixed. Hence the necessity of using only " freshly burnt " lime.

Hydrated Lime.—As explained on p. 20, hydrated lime is that produced when just sufficient water is added to the burnt limestone to satisfy the chemical action of slaking, and is in a dry powder form. The slaking process must be thorough, as any unslaked particles may cause considerable damage.

In addition to ordinary quicklime, certain lime manufacturers now supply lime in hydrated form. There is an increasing demand for this dry hydrated lime on account of the saving of time and labour resulting to the builder or plasterer. This lime is hydrated by a special plant at the lime-works and is supplied in bags, ready for use, in the form of a dry, fine powder. This process must be carefully controlled and the amount of water added must be just sufficient for the purpose, as an inadequate supply would result in some of the lime being unslaked, whilst an excess of water would produce plastic lime or putty.

[1] The B.S.S. No. 890—1940, states that a lime which contains more than 5 per cent. of magnesium oxide shall be termed a magnesian lime.

At the Buxton works referred to on p. 19, hydrated lime, called " Limbux," is produced by the plant shown diagrammatically in Fig. 7. The burnt lime from the kiln is fed into the crusher A and reduced in size from 1-in. down, elevated to the hopper B and passed into the hydrator C. The latter consists of six steel tubes, each 2-ft. 6-in. diameter and 12-ft. long. A carefully regulated supply of water required to slake the lime enters the hydrator at D, the steam generated from the slaked lime rising to heat the water. The lime is pushed forward by means of an auger and traverses the hydrator as indicated by the arrows. It is now in the form of a powder and proceeds to the separator E, where the fan F separates the fine light powdered hydrated lime from the heavier coarser matter. The latter, consisting of clots of hydrated lime and small nodules of unslaked lime, falls to the bottom and the clots are broken up by the pulverizer G. Any unslaked particles of lime, because of their density, fall to the bottom of the pulverizer and are rejected. The hydrated lime extracted by the fan is blown to the cyclone H and hence to the bunker J. The greater part of the circulating air is returned by the pipe L to the separator system. The increased air pressure in the bunker which is created by the fan is relieved by a tube which is terminated by a canvas sieve called the " stockings " M. This allows the air to escape, any of the fine powder drawn up with it being retained and returned to the bunker by periodically striking the canvas on the outside. Finally, the hydrated lime in the bunker, like Portland cement (see p. 22), flows into paper bags and is automatically weighed. The usual size of bag contains 56-lb., but 1 and 2-cwt. bags can be obtained if required.

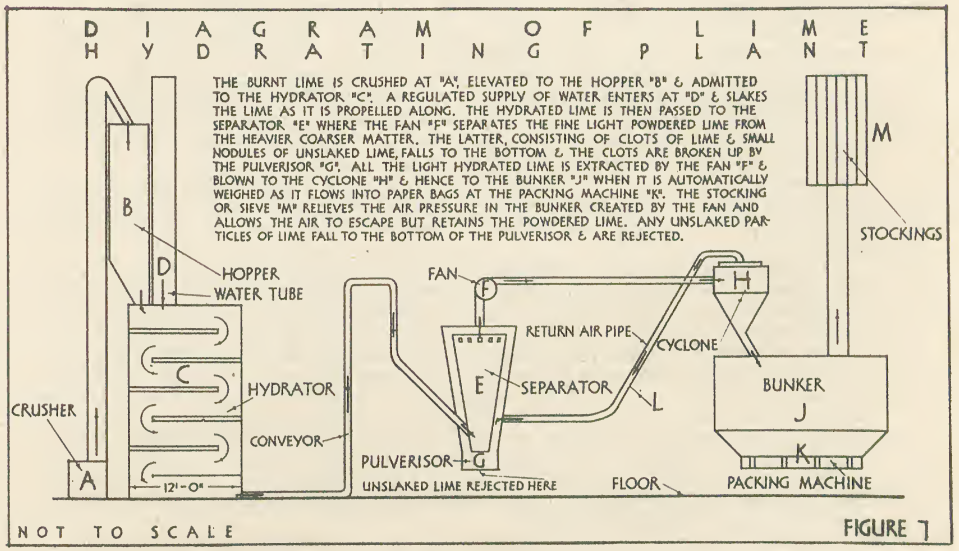


DIAGRAM OF LIME HYDRATING PLANT
THE BURNT LIME IS CRUSHED AT "A", ELEVATED TO THE HOPPER "B" & ADMITTED TO THE HYDRATOR "C". A REGULATED SUPPLY OF WATER ENTERS AT "D" & SLAKES THE LIME AS IT IS PROPELLED ALONG. THE HYDRATED LIME IS THEN PASSED TO THE SEPARATOR "E" WHERE THE FAN "F" SEPARATES THE FINE LIGHT POWDERED LIME FROM THE HEAVIER COARSER MATTER. THE LATTER, CONSISTING OF CLOTS OF LIME & SMALL NODULES OF UNSLAKED LIME, FALLS TO THE BOTTOM & THE CLOTS ARE BROKEN UP BY THE PULVERISOR "G". ALL THE LIGHT HYDRATED LIME IS EXTRACTED BY THE FAN "F" & BLOWN TO THE CYCLONE "H" & HENCE TO THE BUNKER "J" WHEN IT IS AUTOMATICALLY WEIGHED AS IT FLOWS INTO PAPER BAGS AT THE PACKING MACHINE "K". THE STOCKING OR SIEVE "M" RELIEVES THE AIR PRESSURE IN THE BUNKER CREATED BY THE FAN AND ALLOWS THE AIR TO ESCAPE BUT RETAINS THE POWDERED LIME. ANY UNSLAKED PARTICLES OF LIME FALL TO THE BOTTOM OF THE PULVERISOR & ARE REJECTED.
M
STOCKINGS
B
D
HOPPER
WATER TUBE
FAN
F
H
RETURN AIR PIPE
CYCLONE
C
HYDRATOR
E
SEPARATOR
L
BUNKER
J
CRUSHER
CONVEYOR
PULVERISOR
G
K
A
12'-0"
UNSLAKED LIME REJECTED HERE
FLOOR
PACKING MACHINE
NOT TO SCALE
FIGURE 7

CEMENT

There are two groups of cement, *i.e.*, *natural* and *artificial*, but whilst the latter is one of the most important building materials, comparatively little natural cement is now produced. Natural cement is made from nodules consisting of lime (approximately 40 per cent.), clay (50 per cent.) and oxides of iron, etc. (10 per cent.); these lumps are burnt and crushed to a powder, which is a brown colour due to the iron content. Roman cement (produced near

London) and Medina cement (Isle of Wight) are both quick-setting natural cements.

The artificial cement group includes :

(*a*) Portland Cement { (i) Normal or ordinary. (ii) Rapid-hardening. (iii) White. (iv) Blast-furnace.

(*b*) High Alumina Cement.

(*a*) (i) *Normal or Ordinary Portland Cement.*—Chalk or limestone and clay are the raw materials from which this cement is manufactured (p. 2, Vol. I).

The cement works are generally situated near deposits of these raw materials. A brief description of the manufacture and a diagram of a cement works are given in Fig. 8. The processes include : (1) Excavation and preparation of the materials ; (2) mixing and grinding ; (3) burning ; and (4) grinding.

1. *Excavation and Preparation.*—The chalk is won from the limestone quarry by blasting. Gelignite charges are tamped in 6-in. diameter holes drilled at about 15-ft. intervals and at a distance of 15-ft. from the face (see sketch). On instantaneously firing these charges, huge masses of the limestone, amounting to several thousand tons and varying in size from small fragments to large blocks, are dislodged. This loose stone is discharged into wagons from a mechanical navvy (p. 2) and hauled to the *jaw crusher* into which it is tipped and reduced by two powerful metal jaws to a maximum size of 8-in. cubes. The crushed stone passes on to a moving belt and is conveyed to the *cone crusher* which reduces it down to ¾-in. maximum. This is delivered by a belt conveyor to the limestone silo.

The clay is excavated by mechanically dragging a *scraper-bucket* over the clay field ; this is tipped into a *wash mill* (p. 1), and the washed clay, called *slip*, containing about 60 per cent. of water, is pumped through metal pipes to the *clay slip storage tank*.

2. *Mixing and Grinding.*—The chalk from the silo and the clay slip from the tank enter the *wet grinding mill* at A in the correct proportions (approximately 78 per cent. chalk and 22 per cent. clay). This is a cylindrical mill, 37-ft. long by 7 to 8½-ft. diameter, having a chromium steel lining and divided into three compartments by two slotted diaphragms. About 32 per cent. of the mill is occupied by steel balls graded in diameter from 4 to 3-in. in the first compartment, 2½ to 1½-in. in the middle compartment and 1-in. in the last compartment. The mill is caused to rotate at about 20 revs. per min., and as it rotates, the abrasive action of the balls as they strike against each other and against the metal casing grind the material as it comes between them. Fine grinding and thorough mixing reduce the materials to a creamy consistency, called *slurry*, the bulk of which, after leaving the mill, passes through a fine sieve (having a 0·0035-in. mesh); that which fails to pass through the sieve is returned to the mill and re-ground.

After screening, the slurry is conveyed to the *open slurry tank*, which is 66-ft. in diameter and 15-ft. deep, where it is kept agitated by compressed air delivered through perforated pipes at the bottom of the tank. The slurry, now a uniform mixture, is then pumped to the upper or feed end of the kiln.

3. *Burning.*—The kiln is of the rotary type. It is a steel cylinder lined with firebrick, about 306-ft. long and 10-ft. diameter, slightly inclined and mounted on rollers ; it revolves slowly at about 1 rev. per min. The fuel is dry pulverized coal. The raw coal is tipped from the railway trucks at C, elevated to the *raw coal silo*, passed to the *coal mill* where it is finely ground and also dried by hot air conveyed from the kiln by pipe D, elevated to the *pulverized coal hopper* and blown in at the lower or firing end of the kiln—see arrows. The temperature in the lower or burning zone is very intense (a white heat of approximately 2,800° F.) and gradually decreases to 450°–500° F. at the top end, where the gases escape up the chimney stack. Thus the cold slurry, which is fed automatically and continuously, is first dried in the upper zone, and during its passage down the kiln is heated and finally partially fused into clinker. The chalk constituent, as it is heated, is converted into quicklime by the liberation of CO_2 and when subjected to the higher temperature the lime and clay chemically unite to form hard balls (⅛ to ¾-in. in size) of Portland cement, called *clinker*, which is dark brown to black in colour.

This clinker, which is white hot, is cooled as it passes from the kiln at the lower end into drums or cylinders called *coolers*. There are twelve of these coolers, 4-ft. in diameter and at least 20-ft. long, parallel to and attached to the outside of the kiln. A draught of cold air is passed through the cylinders as the clinker gradually gravitates towards and emerges from the lower end on to a belt conveyor which delivers it to the *clinker storage bin* or shed.

4. *Grinding.*—Clinker is fed into the *clinker hopper* by means of an overhead travelling crane grab ; the latter is also used to mix the coarse with the finer clinker. From the hopper the clinker passes to the *combination grinding mill, ball mill* or *dry mill* ; this is of the same size and is similar to the wet mill, it being divided into three compartments which contain graded steel balls. These grind the clinker to a powder which is so fine that at least 90 per cent. of it must pass through a sieve of wire cloth having a mesh of 0·0035-in. square size of openings (see below).

A small quantity, from 1 to 3 per cent., of gypsum (calcium sulphate) is added at B from the *gypsum hopper* which adjoins the clinker hopper. This tends to lengthen the setting time of the cement to suit practical conditions.

The ground cement as it emerges from the dry mill is forced by compressed air up a pipe to silos or bins, each 20-ft. in diameter and about 70-ft. high, and having a capacity of 1,500 tons.

Packing.—The cement from the silos is elevated to a hopper from which it flows to the *packing machine*. The cement was formerly packed into jute bags, but strong paper-valved bags of 1-cwt. capacity are now chiefly used. Each bag is placed by hand on the delivery nozzle of the machine, the cement is automatically weighed as it flows into it, and the filled and sealed bag is discharged and either stacked or placed direct into lorries or trucks. One machine can fill 1,200 bags per hour.

Testing.—The manufacture is closely controlled at each stage, and samples of the clay slip and chalk before they enter the wet mill, slurry after leaving the mill, clinker after leaving the kiln, and cement at the packing machine are taken for laboratory examination.

The cement during and after manufacture is tested in accordance with the British Standard Specification for Ordinary Portland and Rapid-hardening Portland Cements, No. 12—1940.[1] This specification includes the following tests with which Portland cement must comply : (*a*) Fineness, (*b*) chemical composition, (*c*) strength, (*d*) setting time and (*e*) soundness. The following are brief particulars of these :—

(a) *Fineness.*—This is estimated by sieving for fifteen minutes a sample (about 4-oz.) of the cement on a No. " 170 " (0·0035-in. mesh) British Standard sieve, when the residue for ordinary Portland cement shall not exceed 10 per cent. As a general rule the finer the cement the more rapid the strength development of the concrete.

(b) *Chemical Composition.*—This clause in the specification limits the proportion of lime to the silica, alumina and iron oxide, and the ratio of the percentage of iron oxide to that of alumina. It also specifies the maximum percentage of insoluble residue (1 per cent.), magnesia (4 per cent.) and sulphur (2·75 per cent.), in addition to limiting the loss on ignition to 3 per cent.

[1] Published by the British Standards Institution, 28 Victoria Street, London, S.W.1, at 2s. net.

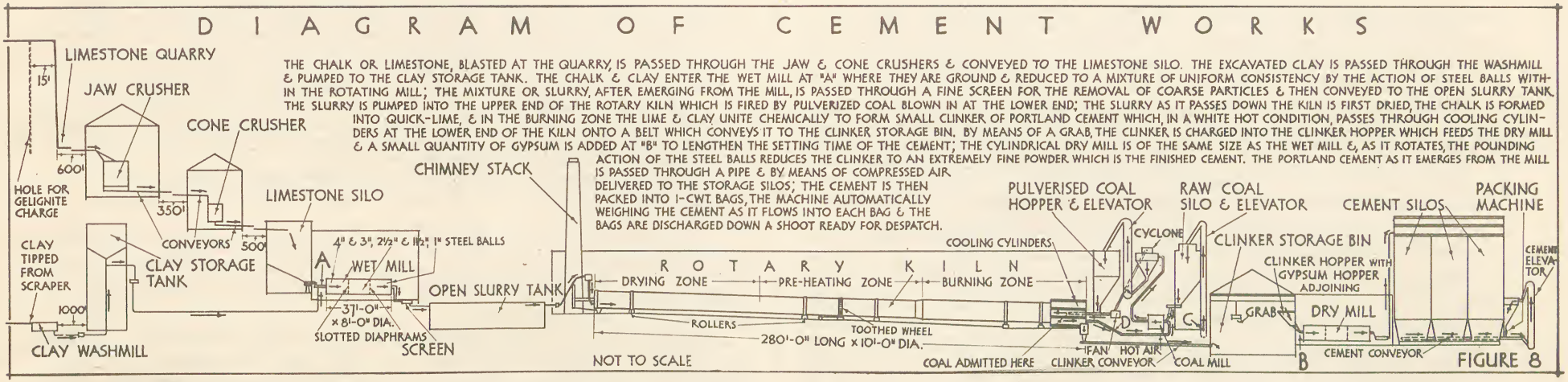


DIAGRAM OF CEMENT WORKS
THE CHALK OR LIMESTONE, BLASTED AT THE QUARRY, IS PASSED THROUGH THE JAW & CONE CRUSHERS & CONVEYED TO THE LIMESTONE SILO. THE EXCAVATED CLAY IS PASSED THROUGH THE WASHMILL & PUMPED TO THE CLAY STORAGE TANK. THE CHALK & CLAY ENTER THE WET MILL AT "A" WHERE THEY ARE GROUND & REDUCED TO A MIXTURE OF UNIFORM CONSISTENCY BY THE ACTION OF STEEL BALLS WITHIN THE ROTATING MILL; THE MIXTURE OR SLURRY, AFTER EMERGING FROM THE MILL, IS PASSED THROUGH A FINE SCREEN FOR THE REMOVAL OF COARSE PARTICLES & THEN CONVEYED TO THE OPEN SLURRY TANK. THE SLURRY IS PUMPED INTO THE UPPER END OF THE ROTARY KILN WHICH IS FIRED BY PULVERIZED COAL BLOWN IN AT THE LOWER END; THE SLURRY AS IT PASSES DOWN THE KILN IS FIRST DRIED, THE CHALK IS FORMED INTO QUICK-LIME, & IN THE BURNING ZONE THE LIME & CLAY UNITE CHEMICALLY TO FORM SMALL CLINKER OF PORTLAND CEMENT WHICH, IN A WHITE HOT CONDITION, PASSES THROUGH COOLING CYLINDERS AT THE LOWER END OF THE KILN ONTO A BELT WHICH CONVEYS IT TO THE CLINKER STORAGE BIN. BY MEANS OF A GRAB, THE CLINKER IS CHARGED INTO THE CLINKER HOPPER WHICH FEEDS THE DRY MILL & A SMALL QUANTITY OF GYPSUM IS ADDED AT "B" TO LENGTHEN THE SETTING TIME OF THE CEMENT; THE CYLINDRICAL DRY MILL IS OF THE SAME SIZE AS THE WET MILL &, AS IT ROTATES, THE POUNDING ACTION OF THE STEEL BALLS REDUCES THE CLINKER TO AN EXTREMELY FINE POWDER WHICH IS THE FINISHED CEMENT. THE PORTLAND CEMENT AS IT EMERGES FROM THE MILL IS PASSED THROUGH A PIPE & BY MEANS OF COMPRESSED AIR DELIVERED TO THE STORAGE SILOS; THE CEMENT IS THEN PACKED INTO 1-CWT. BAGS, THE MACHINE AUTOMATICALLY WEIGHING THE CEMENT AS IT FLOWS INTO EACH BAG & THE BAGS ARE DISCHARGED DOWN A SHOOT READY FOR DESPATCH.
LIMESTONE QUARRY
15'
JAW CRUSHER
CONE CRUSHER
600'
350'
HOLE FOR GELIGNITE CHARGE
CONVEYORS
500'
LIMESTONE SILO
CHIMNEY STACK
CLAY TIPPED FROM SCRAPER
CLAY STORAGE TANK
4" & 3", 2½" & 1½", 1" STEEL BALLS
A
WET MILL
37'-0" × 8'-0" DIA.
SLOTTED DIAPHRAGMS
OPEN SLURRY TANK
SCREEN
1000'
CLAY WASHMILL
NOT TO SCALE
ROTARY KILN
DRYING ZONE
PRE-HEATING ZONE
BURNING ZONE
ROLLERS
TOOTHED WHEEL
280'-0" LONG × 10'-0" DIA.
COOLING CYLINDERS
PULVERISED COAL HOPPER & ELEVATOR
CYCLONE
RAW COAL SILO & ELEVATOR
CLINKER STORAGE BIN
CLINKER HOPPER WITH GYPSUM HOPPER ADJOINING
GRAB
DRY MILL
CEMENT SILOS
PACKING MACHINE
CEMENT ELEVATOR
D
C
B
FAN
HOT AIR
COAL ADMITTED HERE
CLINKER CONVEYOR
COAL MILL
CEMENT CONVEYOR
FIGURE 8

The following may be considered as an approximate analysis of a typical Portland cement :—

	Per Cent.
Lime	64
Silica	23
Alumina	5
Iron oxide	3
Magnesia	2
Sulphuric anhydride	2
Soda and potash	1
	100

The whole of the lime should combine with the silica and alumina. Any excess, called *free lime*, may produce unsoundness (see p. 24). A deficiency of lime may produce a weak cement.

The presence of iron is responsible for the grey colour of cement (resembling that of Portland stone). If excessive, the iron oxide increases the difficulty of grinding the clinker.

Excessive quantities of magnesia and sulphur compounds cause unsoundness.

An excessive quantity of soda and potash may cause efflorescence in the cement, and these alkalis should therefore be kept to a minimum.

(c) *Strength.*—The specification requires that cement shall pass tests to determine its strength in tension or compression.

Tensile Strength Test.—The cement has to be mixed with sand to form a mortar composed of 1 part (by weight) cement and 3 parts of Leighton Buzzard sand (a very clean, white and well graded sand obtained from Bedfordshire) to which a specified amount of water is added. The mortar is formed in a brass mould of the shape shown at B, Fig. 9, the cross-sectional area at the "waist" of the briquette being 1 sq. in. The mould is carefully filled by consolidating the mortar with a standard steel spatula (knife) until it is flush with the top; the mould is reversed and the broad blade of the spatula is used to pat the mortar until water is brought to the surface, after which the surface is smoothed over and brought flush with the top of the mould by a trowel. The briquette is stored in a damp atmosphere and kept for twenty-four hours at a temperature of 58° to 64° F., when it is removed from the mould, submerged in clean water and left until required for testing.

It is required that twelve briquettes shall be prepared and stored in this manner, and that six of these shall be tested at three days after moulding, followed by the remaining six at seven days. The average minimum tensile breaking strength of ordinary Portland cement shall be 300-lb. per sq. in. at three days and 375-lb. per sq. in. at seven days after moulding.

One type of tensile testing machine is shown at A, Fig. 9. This has a pair of jaws of standard size and shape in which the briquette is placed. The lower jaw is fixed and the upper jaw is suspended at K to a system of levers consisting of lever R, pivoted on a knife-edge at J, and connected by a rod (having knife-edges at L and M) to lever Q, pivoted at N. A bucket is suspended at P to receive the load in the form of *shot* (lead pellets) fed from the container.

The testing is carried out in the following manner: A briquette is placed in the jaws, the spindle T is lifted to release the shot, which passes in a steady stream through a valve down the nozzle of the container into the bucket. This load is transmitted to the briquette through the system of levers and ultimately causes it to break across at the waist. Immediately this occurs the flow of shot is automatically stopped as the bucket falls on the pedestal below, depressing arm S, which in turn causes the spindle to drop and close the valve of the container. The bucket containing the shot is placed on some scales and weighed. A direct reading of the breaking load in pounds is obtained from the scales, as they are calibrated in accordance with the ratio of the levers after the weight of the empty bucket has been allowed for. As this breaking load is applied on 1 sq. in. of the briquette, it becomes the breaking stress in pounds per square inch.

A line diagram of the lever system of the apparatus is shown at C. The ratio of the lengths J′K′ and J′L′ in the lower lever is as 1 : 5 and that of M′N′ and N′P′ is as 1 : 10. Hence the magnifying ratio is 50, *i.e.*, the stress on the briquette is 50 times as large as the load in the bucket. Thus, if the weight of the shot in the bucket when the briquette fails is 7-lb., the load acting on ML equals $\frac{7 \times 10}{1} = 70$-lb., and this multiplied by 5 equals 350-lb. This is the breaking load, and is that which is read directly from the scales.

Compressive Strength Test.—If required by the purchaser the above tensile stress test may be substituted by a compressive strength test. The latter is applied to 2·78 or 3-in. cubes of a 1 : 3 mix, the mixing and compacting by vibration in a machine being specified. Three cubes are tested in a compression machine (see p. 32) at three days after moulding, and the average minimum compressive strength (calculated from the crushing load) for ordinary Portland cement shall be 1,600-lb. per sq. in. Three cubes are similarly tested at seven days, when the average minimum compressive strength shall be 2,500-lb. per sq. in. (see Table II, p. 34).

(d) *Setting Time.*—When cement and water are mixed to form a paste, the mass

remains plastic for a short while. The water combines chemically with the grains of cement to form hydrates. This is known as *hydration*. As this proceeds, the plasticity gradually disappears and the cement stiffens or *sets*. The cementing material between the particles of cement increases in amount, causing the mass to gain in strength and *hardness*, and this hardness increases for some considerable time after it has set.

The specification refers to " initial set " and " final set." Regarding the former, it is essential that the cement shall set slowly at first to allow time for the mixing and placing in position of the concrete, and to ensure thorough adhesion between adjacent batches of concrete. It is equally important that the concrete shall harden quickly after its initial set in order that it may be loaded as soon as possible and (in the case of reinforced concrete) permit of the early removal of any formwork or shuttering (temporary timbering) which may be supporting it.

According to the specification, the initial setting time for normal setting cement shall be not less than thirty minutes and the final setting time not more than ten hours. If a quick-setting cement (see next column) is required, the initial setting time is reduced to not less than five minutes, and the final setting time to not more than thirty minutes. The Vicat apparatus, shown at D, Fig. 9, is used to determine the initial and final setting times of cement. A brass cylindrical mould, approximately 3-in. dia. and 1½-in. deep, is placed upon a metal plate and filled to the top with neat cement to which sufficient water has been added to make it plastic. The filled mould is placed on the base as indicated by broken lines. The initial set is measured by means of a needle having a flat end, 0·039-in. (1-mm.) square, which is screwed to the bottom of the rod in place of the final setting needle shown. The pin is withdrawn and the rod is lowered until it touches the smooth surface of the cement, when it is quickly released and allowed to penetrate the cement. This is repeated at intervals on different parts of the specimen until the needle fails to pierce it completely. The time which has elapsed between the addition of the water and this partial penetration of the needle is called the initial setting time and, as already stated, must not be less than thirty minutes for normal setting cement (or five minutes for quick-setting cement). The final setting time is determined in a similar manner, the initial setting needle being replaced by the final setting needle shown. The latter, of the same shape and section as the former needle, has a metal fitting attached at the end ; the base of the fitting has a raised rim which is about 0·02-in. (½-mm.) above the end of the central needle. The cement is considered to be finally set when, on a gentle application of the needle, the central flat point makes an impression on it, but the raised rim fails to do so. This final setting time must not exceed ten hours for normal-setting cement or thirty minutes for quick-setting cement.

(e) *Soundness.*—Unsound cement has a tendency towards excessive expansion. Sound cement is relatively free from this tendency and its volume remains constant. Most serious defects in cement products are caused by expansion which takes place during setting and may continue for some considerable time. Thus, reinforced concrete made of unsound cement may crack and disintegrate to such an extent as to permit the entrance of moisture and cause corrosion of the exposed steel. The soundness test which appears in the standard specification is therefore very important.

This soundness or expansion test is carried out in the Le Chatelier apparatus illustrated at F, Fig. 9. This is a brass split cylindrical mould having an indicator attached on each side of the split. The mould, resting on a glass plate and held together with the split edges touching, is completely filled with neat cement gauged with just sufficient water to make it plastic, and covered with another glass plate which is held down by a small weight. It is at once immersed in water (temperature 58° to 64° F.) and left for twenty-four hours. It is taken out, the distance W between the indicators is measured, the weighted mould is again immersed and then boiled for three hours. The mould is removed and, after cooling, the distance between the points is again measured. The difference between the two measurements indicates the expansion of the cement and shall not exceed 0·4-in (10-mm.).

Good cements will show little (not more than 0·04-in.) if any expansion. The expansion of poor cements is often due to the presence of excess gypsum and other sulphates. The boiling water accelerates the reaction and resultant expansion.

A simple but effective test (not mentioned in the specification) is the *hot-pat test*. Water is added to neat cement and thoroughly mixed to a plastic condition. This is worked to the shape of a ball, placed on a piece of glass which is tapped on the bench until the cement flattens out to the shape of a disc about 3-in. in diameter, a little more than ¼-in. thick at the centre and tapering to a knife-edge at the circumference. The surface is then smoothed over with a knife. After being covered over with a damp cloth and allowed to harden for twenty-four hours, the pat is boiled in water for four or five hours. If the cement is unsound, radial cracking (especially at the edges) and distortion will appear, due to expansion ; the edges may curl up and surface flaking may appear. A pat of sound cement will remain unaltered after this treatment, although fine shrinkage cracks may appear.

The *cold-pat test* is similar to the above, except that the pat is not boiled but simply immersed in cold water for twenty-four hours before examination.

(*a*) (ii) RAPID-HARDENING OR HIGH-EARLY-STRENGTH PORTLAND CEMENT.—This is true Portland cement, and, as its name implies, its chief characteristic is the comparative rapidity with which it gains in strength in the early stages of hydration (see Table II, p. 34).

The B.S.S. No. 12—1940, already referred to, applies to this cement. Whilst the residue of ordinary cement on a 170 sieve shall not exceed 10 per cent. (see p. 22), that of rapid-hardening cement shall not exceed 5 per cent. The ultimate tensile stress shall be not less than 300-lb. per sq. in. after one day and 450-lb. per sq. in. after three days. The compressive strength shall be not less than 1,600-lb. per sq. in. after one day and 3,500-lb. per sq. in. after three days. The initial setting time shall be not less than five minutes and the final setting time shall be not more than thirty minutes. These requirements should be compared with those stated in respect to ordinary Portland cement.

Rapid-hardening cement can be usefully employed in cold weather, as it is less liable than ordinary cement to damage from frost. It is preferred to ordinary cement in the construction of concrete roads, as it can take traffic within a few days, whereas concrete composed of ordinary cement should be left for twenty-eight days before roads are opened to heavy traffic. This advantage also applies to reinforced concrete floors, etc., made of rapid-hardening cement, as the lapse of time before the removal of the temporary timbering (formwork) and the application of loads is considerably reduced. The cost of rapid-hardening cement is slightly more than that of ordinary Portland cement. " Ferrocrete " and " Vitocrete " are some of the well-known brands of rapid-hardening cement.

(*a*) (iii) WHITE PORTLAND CEMENT.—The chemical composition and characteristics of white Portland cement are similar to those of ordinary Portland cement, except that the latter is of a grey colour. The colour of white cement is due to the raw materials used and the special precautions taken in its production. The materials are pure limestone and china (white) clay, the iron oxide content (which imparts the grey colour to ordinary Portland cement) being less than 1 per cent. The cement must not come into contact with iron or steel during its manufacture, the kiln is lined with special fireclay blocks, and oil is generally the fuel used. Aggregates used with white cement should

be light coloured (see p. 28). White cement is more expensive than ordinary cement. It is in increasing demand for external rough-casting of walls, pointing of brickwork and masonry, and in the manufacture of reconstructed (artificial) stone and tiles. Well-known brands include " Atlas " and " Snowcrete."

COLOURED CEMENT.—Cement, used for special purposes such as for plastering walls and in the manufacture of reconstructed stone and tiles, is now obtainable in a variety of colours. Pigments, such as black oxide of iron and manganese black (to produce a black colour), red oxide of iron (producing red), brown oxide of iron (producing brown), chromic oxide (producing green), etc., are thoroughly incorporated with the cement in a dry condition by machinery. Coloured cement can be obtained ready for use from the manufacturers, or the cement and pigments can be mixed on the job.

(*a*) (iv) PORTLAND BLAST-FURNACE CEMENT.—This is a mixture of ordinary Portland cement and blast-furnace slag. The latter is a product of the blast furnace in which iron ore is smelted as a preliminary in the manufacture of cast iron, steel, etc. Normally this slag is an impurity which is run into ladles and conveyed to the slag tip. When, however, it is used in the production of cement, the slag as it issues from the furnace is cooled by a stream of water which reduces it to a honeycombed, granulated condition. The slag is removed, dried and mixed with ordinary cement clinker and passed to a ball mill (see p. 22) for thorough incorporation and fine grinding. Not every slag is suitable for this purpose. The quality of this cement must comply with the British Standard Specification for Portland-Blastfurnace Cement, No. 146—1932. The proportion of slag must not exceed 65 per cent., and that of Portland cement clinker must not be less than 35 per cent. (see p. 28).

(*b*) HIGH ALUMINA OR ALUMINOUS CEMENT.[1]—There is a considerable difference in both composition and manufacture between this cement and Portland cement. Aluminous cement is made from a mixture of limestone and bauxite (aluminium ore imported principally from Baux, France) which are fired in a furnace in which pulverized coal and a hot air blast are employed. The heat fuses (liquefies) the materials, whereas in the manufacture of Portland cement the heat clinkers the raw materials (see p. 22). The liquid cement is tapped from the base of the furnace and conveyed to mills where it is ground to extreme fineness. The cement is much darker in colour than Portland cement. An approximate analysis is :

	Per Cent.
Lime	39
Silica	7
Alumina	39
Iron oxide	13
Magnesia, etc.	2
	100

This cement is sometimes produced in electric furnaces and known as *electric cement*.

[1] *Various tests are embodied in the British Standard Specification for High Alumina Cement, No. 915—1940.*

Its chief characteristics are : Rapid-hardening, great strength, large amount of heat generated during the setting and hardening process, and its resistance to acids. Concrete composed of this cement develops a compressive strength of at least 5,000-lb. per sq. in. at the age of one day and 7,000-lb. per sq. in. at the age of seven days (see Table II, p. 34). It is unaffected by frost on account of the heat which it generates. Because of these qualities, high alumina cement can be usefully employed when formwork is required to be removed with the minimum delay, for concreting ground floors on certain soils containing sulphates which may attack ordinary Portland cement concrete, for concrete piles (which can be driven after three days' hardening), for road construction (especially in the re-laying of city streets), for general work requiring great strength, and when work must be done during low temperatures. The strength of high alumina cement concrete is affected adversely if the heat rapidly generated during hardening is not got rid of. Thus, formwork encasing concrete should be removed as soon as practicable. Its use is not advocated for mass concrete exceeding 18-in. thick unless it can be deposited in thin layers, preferably 12-in. thick, and the dissipation of the evolved heat permitted. Another disadvantage of high alumina cement is its relatively high cost. It must not be mixed with or brought into contact with Portland cement, as a reduction in the strength of the former will result. Well-known brands are " Ciment Fondu " (fused cement) and " Lightning."

MORTARS

Mortar is composed of an aggregate, such as sand, and a matrix or binding material of lime or cement or both (see p. 2, Vol. I).

SAND in mortar (1) reduces shrinkage and without it cracks would develop, (2) assists in the hardening of pure limes especially (p. 20) by allowing the penetration of air which provides CO_2 for the development of carbonization (p. 20) and (3) reduces its cost, as sand is much cheaper than lime or cement.

To give the best results sand should be well graded and must be clean.

Grading of Sand.—A suitably graded sand consists of particles varying in size from coarse to fine, with the smaller particles packing into the voids between the larger. A *coarse* sand is one the bulk of which is retained on a No. 52 British Standard Sieve ($\frac{1}{8}\frac{1}{4}$-in. square mesh). If most of the particles of a sample pass through this sieve, the sand is classified as a *fine* one. Coarse sand produces what is known as a *harsh* mortar. Sand containing a large proportion of very fine particles, such as dust or silt, is not suitable, as an excessive amount of water is required to make the mortar workable, and this reduces its strength and increases shrinkage. It is therefore recommended that, for mortar, not more than 3 per cent. of sand should pass a No. 100 standard sieve ($\frac{1}{1}\frac{1}{0}\frac{1}{0}$-in. square mesh). To the experienced, the relative coarseness and fineness of a consignment of sand can be gauged approximately by its appearance and by rubbing some of it between the thumb and forefinger.

The strength of mortar (and concrete, see p. 28) is decreased if the particles

of sand are of uniform size, owing to the presence of a large proportion of pore spaces. Tests have shown that the shape of the particles is not very important.

Cleanliness of Sand is most essential. Adhesion between the binding material and the sand is only possible if the particles of the latter are clean, and the presence of dirt, especially if finely distributed to such an extent as to surround each small particle, interferes with the setting and reduces the strength of mortars and concretes. The chief impurities are clay, loam and organic compounds such as vegetable matter. The latter, not being inert, is liable to decay, and the organic acids produced may have an ill-effect on the mortar or concrete.

Clean sand when rubbed will not stain the fingers. A simple and effective test consists of half filling a glass vessel with the sand, water is added until it almost reaches the top, and after being agitated, the sand is allowed to settle. If the sand is clean, not more than a thin film of silt will be seen deposited on top of the sand, and the water above it will be clear; if, however, the sample is a dirty one, the bottom layer of the washed sand will be covered by a relatively thick dark layer of dirt, and small particles of suspended matter (generally organic and fine clay) may be seen floating in the water even if several hours have elapsed after agitation and examination.

Sand for general purposes may be considered satisfactory if a test similar to the above (but in a measuring cylinder) shows that it contains not more than 6 per cent. of silt. This is known as a *sedimentation* or *decanting test.*

A test for organic impurities consists of comparing the colour of the water above the sample of sand in a cylinder (to which a definite amount of 3 per cent. sodium hydroxide solution has been added) with that of a standard solution of tannic acid and sodium hydroxide. If, after standing for twenty-four hours following agitation, the colour of the former is darker than the standard colour, it indicates that the sand contains an excessive amount of organic matter which may be injurious and should be treated with suspicion.

If, on the score of economy, a local sand is to be used which is not sufficiently clean, much of the dirt can be eliminated by washing.

The following aggregates are used for mortars: (1) Pit or quarry sand, (2) river sand, (3) sea sand, (4) crushed stone and (5) ashes.

1. *Pit or Quarry Sand.*—The quality varies. Provided it is clean, it is a very good sand for mortar, concrete and plaster. Some pit sands are liable to contain organic matter in the form of coal which may interfere with the setting.

2. *River Sand.*—This is usually clean and is an excellent sand for all purposes. Some river sands may be deficient in *fines* (smaller particles) and thus produce harsh mortars.

3. *Sea Sand.*—Whilst this sand is commonly used locally for concrete, it is not suitable for mortar on account of its salt content which causes efflorescence (p. 13).

4. *Crushed Stone.*—This is now often used, especially for mortar required for ashlar work. The waste stone at the quarries is crushed to the size of sand particles. When this crushed stone is the same as that used for the ashlar work it assists in producing a mortar which closely conforms to the colour of the masonry and thus helps in making the joints inconspicuous.

5. *Ashes or Clinkers* from furnaces are crushed very finely and intimately ground with the lime in a mortar mill to produce a cheap and strong mortar, known as *black mortar.* The ashes should be free from unburnt coal and dust. Old broken bricks, which should be clean and especially free from plaster, are sometimes crushed and mixed with the lime in the mill.

Lime Mortar.—The slaked lime is mixed with the aggregate and water either by hand or in a mortar mill. Manual mixing should be done on a boarded platform to ensure that dirt will not be shovelled into the mix. The period of slaking, composition and strength of mortar depend upon the class of lime used.

The properties of the mortar should resemble those of the bricks. Thus, whilst a dense, strong impermeable mortar, such as cement mortar, should be used for bedding, jointing and pointing strong bricks of the engineering class, such mortar would be unsuitable for low-strength bricks of medium permeability if used in the construction of external walls. Existing brickwork has been known to develop defects in the bricks subsequent to re-pointing with rich, dense mortar. A possible explanation of the cause of this is that water absorbed by the bricks during wet weather can only be eliminated during dry periods by evaporation on the surface of the bricks and not through the joints, and any salts in the bricks may crystallize near the surface, causing disintegration of their faces.

Non-hydraulic Lime Mortars (from pure and lean limes, see p. 20) must be well slaked before use. This type can be stored in a heap for several days after mixing, provided the surface is smoothed over with a shovel to minimize carbonation by the exclusion of as much air as possible. As such mortars can only harden when exposed to the atmosphere (p. 20), a relatively large proportion of sand must be added to the lime to assist in the penetration of air. For this reason the proportion of sand may be as high as 4 parts by volume of sand to 1 part lime. These mortars are light-coloured. They are not likely to cause efflorescence. These mortars are not suitable for work below ground level, especially if the ground is water-logged. Such mortars are improved if gauged with cement (p. 27).

Hydraulic Lime Mortars (see p. 20) should be used within one hour after being mixed. This especially applies to eminently hydraulic mortar which sets quickly after the addition of the necessary amount of water. Any mortar which has stiffened and cannot be knocked up by means of a trowel to a sufficiently plastic condition should never be used. The proportions of lime to aggregate range from 1 part lime to from 2 to 3½ parts sand, a common mixture being 1 : 3. These are excellent mortars for all purposes and are particularly suited for work below the ground level and in exposed positions.

Eminently hydraulic lime mortars rank next to cement mortars as regards strength. They may be a cause of efflorescence (p. 13) owing to the presence of salts.

Magnesian or Dolomitic Lime Mortars (see p. 21) have a slow-setting action and they should therefore be slaked for several hours before use. Their properties and uses are somewhat similar to those of hydraulic lime mortars.

Dry Hydrated Lime (p. 21) should be reduced to a putty consistency by the addition of water and allowed to stand (*soak*) for about two days before being mixed with sand.

Black Mortars (see p. 26).—A common proportion is 1 part lime to 3 parts ashes or clinker (mixed in the mill). They are hard-setting mortars and are suitable for internal walls and for brickwork and masonry where the colour is not objected to.

Cement Mortar (see p. 2, Vol. I).—It is stronger than lime mortar and is therefore used in the construction of piers and load-bearing walls ; it is also usefully employed for work below ground level and for external walls in exposed positions on account of its impermeability. Cement mortar is now extensively used during winter, as it is not so liable to damage by frost, owing to its relatively quick-setting property. It must be used immediately after mixing. Efflorescence may be caused, due to the presence in the cement of carbonates and sulphates of potash and soda (see p. 13). The usual composition is 1 part cement to 3 parts sand ; tests have shown that nothing is gained by using a richer (and more costly) mix than this, provided the sand is well graded. A dense cement mortar should not be used for bedding and jointing low-strength bricks (p. 26).

Lime-cement or Compo Mortars.—Compo is a mixture of lime, cement and sand. It is usual to mix the lime mortar as already explained, and then *gauge* (add to) this mixture with the necessary proportion of Portland cement immediately before the mortar is required for use. Only non-hydraulic and feebly hydraulic limes should be used for this class of mortar. The addition of the cement increases the hydraulicity of the mortar, besides increasing its strength, and the rate of hardening is therefore accelerated. This quality makes it a useful mortar to be employed in winter. Compo is more open textured than cement mortar and is therefore better suited for bedding and jointing bricks of moderate or low strength. The gauging also increases the workability of the mortar. The proportions vary from 1 part cement : 2 to 3 parts lime : 9 to 12 parts sand. Eminently hydraulic and magnesian limes should not be gauged with cement.

Compo is an excellent mortar for rubble, flint and similar walling where a large proportion of bedding material is required. When ordinary lime mortars are used for this class of work there is a tendency for excessive shrinkage to take place, and this may cause cracks through which water may penetrate. Compo for such work may consist of 1 part cement : 4 parts lime : 12 parts sand.

Fire-resistant Mortar.—Ordinary lime and cement mortars are unsuitable for setting firebricks or fireclay blocks used for lining furnaces, fireplaces, etc., as they shrink considerably when subjected to heat. There are several proprietary mortars specially produced for this class of work. A good fire-resisting mortar consists of a mixture of 1 part cement (preferably aluminous cement, see p. 25) to 2 parts finely crushed firebrick (p. 16).

Strength of Mortar.—Cement mortar produces the strongest brickwork, non-hydraulic lime mortar walling is approximately half the strength of that in cement mortar, and the strength of eminently hydraulic mortars is intermediate between that of cement and non-hydraulic lime mortars. The strength of compo mortars depends a good deal upon the cement content and may be very little less than cement mortar.

Colour of Mortar.—Whilst the colour of the mortar is immaterial if the brickwork is to be covered with plaster or roughcast, it is very important that the colour shall suitably conform with that of the bricks when these are to be used in the construction of faced work. The appearance of brickwork is often spoilt through inadequate attention being paid to the colour and texture of the jointing material, even when the bricks are expensive facings. The colour of mortar is influenced by both the lime or cement and the aggregate, and in order to obtain the desired result it is sometimes essential to try out different materials and proportions.

The colour of lime mortar varies from white (when pure lime—p. 20—is used) to black (preceding column). Ordinary Portland cement mortar is grey in colour ; white Portland cement with a light-coloured sand produces white mortar ; different shades can be obtained by using coloured cements (p. 25). Sand varies in colour from white to dark brown or red. A yellow sand, mixed with a grey lime, produces a satisfactory colour for certain sand-faced brickwork.

Multi-coloured brickwork especially is apt to be disfigured by iron stains. As this staining disappears after the brickwork has weathered, it is advisable to defer the pointing of such brickwork.

In masonry, and in order that the mortar shall harmonize with the stone, it is a common practice to use crushed stone (p. 26) in lieu of sand. Thus, for Portland stone ashlar work the proportions recommended are 2 parts Portland cement : 5 parts slaked lime : 7 to 12 parts crushed Portland stone.

Waterproofed Mortars.—There are now available a large number of proprietary substances, called *waterproofers*, which are mixed with mortars to render them impervious. They are marketed in the form of powders, pastes and liquids. Their object is to either fill the pores of the mortar or to line the pores with a film of water-repellent material. Most of these, such as " Cementone," " Medusa," " Pudlo " and " Sika," are only suitable for cement mortars. As such mixtures must not be used after the initial set, it is necessary to apply the material without delay and in some cases within half an hour after the water has been added. Unused partially set mortar must be discarded.

The amount of waterproofer added varies and should be in accordance with the manufacturers' instructions. When in powder form, the mixture may consist of 1 part cement : 2 to 4 parts sand : 2 to 5 per cent. of the waterproofer ; the required amount of the powder is added to and well incorporated with the cement before being spread over the sand ; the whole is then mixed dry before the water is carefully added, after which it is mixed to an even consistency. When in the form of a paste, water is added very gradually to the waterproofer in the usual proportion of 1 part paste to 10 parts water whilst being well stirred to reduce the solution to a uniform consistency ; the cement and sand are well mixed dry before the solution is added, and then mixed wet to a workable condition. If in liquid form, it is usual to add 1 gal. of the waterproofer to every 15 gals. of water ; the cement and sand are mixed dry before this " gauging water " is added and finally mixed wet.

Further reference to waterproofers is made on p. 36.

CONCRETE

Concrete consists of a (1) matrix, (2) fine aggregate and (3) coarse aggregate thoroughly mixed with water. In general, a good concrete is required to be hard, strong, durable, dense, non-porous, fire-resisting and economical, although for certain structures, such as internal partitions, strength and impermeability are not necessary requirements where a porous concrete may be desirable on account of its lightness and sound-insulating properties. The characteristics of concrete are influenced by the quality of the materials, grading of the aggregates, proportioning, amount of water used, and workmanship. Ideally, the variation in the size of the aggregates (known as *grading*) should be such that the fine aggregate will fit into the spaces between the coarse aggregate to leave a minimum percentage of voids to be filled by the matrix in cementing the whole mass together. Adequate grading is economical, as less cement is needed when the aggregates are well graded. A mixture which is too rich in cement may shrink excessively. It is most important to appreciate that the strength of mortar depends very largely upon the amount of water used in relation to the cement; *an excess of water results in a considerable reduction in strength* (see p. 30). Just sufficient water should be added to make the mix reasonably plastic and workable.

The expression "workable mixture" is applied to concrete of such consistency that it can be readily deposited in position in a uniform condition and rendered dense after a reasonable amount of punning (see p. 35).

Concrete when used by itself is known as *mass concrete* (used for foundations, certain floors, retaining walls, etc.); concrete reinforced with steel is called *reinforced concrete*.

1. MATRIX.—The binding material used for most concretes is ordinary Portland cement (pp. 21 to 24). Rapid-hardening cement (p. 24) is suitable as a matrix for concrete structures which have to be speedily constructed. The fire-resisting and durable qualities of blast-furnace cement (p. 25) render this a satisfactory matrix for reinforced concrete and marine work. High alumina cement (p. 25), because of its high strength and rapid-hardening characteristics, is especially suited as a binding material for concrete used in structures which are to withstand high stresses and be speedily erected. Hydraulic lime is now very rarely employed as a concrete matrix, it having been displaced by cement for this purpose.

2. FINE AGGREGATE.—According to the Recommendations for a Code of Practice for the Use of Reinforced Concrete in Buildings,[1] a fine aggregate is classified as one which will pass through a sieve having a $\frac{3}{16}$-in. square mesh. Sand (p. 25) is the chief material employed as a fine aggregate, and both quarry and river sands are extensively used for this purpose. Sea sand is also used locally as an aggregate, chiefly because of its low cost; if such sand is required for concrete which is to be exposed to view, it is advisable to eliminate as much as possible of the salt content by washing with *fresh* water, otherwise efflorescence may be objectionable. Cleanliness and suitable grading, already referred to, are essential requirements.

[1] See footnote to p. 29.

3. COARSE AGGREGATE.—This is classified as material which is retained on a $\frac{3}{16}$-in. square meshed sieve. The maximum size varies; thus, for reinforced concrete work it is usually $\frac{3}{4}$-in., and for mass concrete, as for foundations, it is generally $1\frac{1}{2}$-in. and may be $2\frac{1}{2}$-in. The materials must be clean (to ensure the thorough adhesion of the cement and the development of the setting properties of the concrete), strong (to resist stresses), durable (to withstand alternate weather conditions of wetness and dryness, frost and thaw, etc.), suitably graded (for economy and the development of the strength and workability of the concrete), free from combustible material (to ensure adequate fire-resistance) and inert in the presence of water (otherwise disruption of the concrete may result by expansion and contraction movement). In addition, aggregate for concrete floors and roads should be effective in resisting abrasion. Flaky and laminated material should be avoided.

The following materials are used for coarse aggregate: (*a*) Broken brick, (*b*) broken stone, (*c*) gravel, (*d*) slag, (*e*) pumice, (*f*) breeze and clinker, (*g*) foamed slag and (*h*) expanded slate. See also *sawdust concrete* and *fibrous wood cement* (p. 47, Vol. III).

(a) *Broken Brick.*—Old bricks from demolished buildings, etc., are broken for use as aggregate. This is a good aggregate, provided the bricks are not porous and are thoroughly cleaned, *i.e.*, any lime and plaster must be removed. Soft and porous brick aggregate is particularly unsuited for reinforced concrete work, as such admits air and moisture to cause corrosion of the steel; broken well-burnt brick aggregate makes a valuable concrete because of its strong, durable and fire-resisting qualities. Adherent lime and plaster are very objectionable, as any calcium sulphate may cause expansion and disintegration of the concrete. Bricks having a high sulphur content are also unsuitable. Broken brick aggregate should be well watered before being mixed to prevent excessive absorption of the water used in mixing which may cause the concrete to crack.

(b) *Broken Stone* is an excellent aggregate provided the stone is free from any undesirable mineral constituents and is not soft, porous, friable or laminated. Granites, sandstones and close-grained limestones are all suitable. The stone is crushed and then screened.

There are several forms of crushers, such as the jaw, hammer, disc, gyratory and roll types, which break up large blocks of the rock into small pieces. There are also several types of screens, most of which have a vibrating action. In screening, the material is passed from the crusher by a belt conveyor to the primary screen, which has a large (3-in.) mesh. The screened material is then passed successively through a series of screens of various sized meshes, *i.e.*, $1\frac{1}{2}$-in., $\frac{3}{4}$-in. and $\frac{3}{16}$-in. Thus, the 3-$1\frac{1}{2}$-in. grade is retained on the $1\frac{1}{2}$-in. sieve and passed to the stock bin, that which passes through it is discharged on to the $\frac{3}{4}$-in. sieve which separates the $1\frac{1}{2}$-$\frac{3}{4}$-in. grade (discharged to a second stock hopper) and allows the finer material to pass through on to the $\frac{3}{16}$-in. sieve to be separated into $\frac{3}{4}$-$\frac{3}{16}$-in. and finer grades, each of which is conveyed to a stock bin.

(c) *Gravel* is another very good aggregate and is extensively used. It is hard and durable, and is obtained from river beds, the seashore, and inland deposits which are quarried. The gravel is excavated by hand labour or mechanically. Clay is a common impurity and must therefore be removed by washing. Seashore gravel, if required for reinforced concrete, should also be washed in fresh water so as to eliminate as much as possible of the salts. This is also known as ballast (see below).

(d) *Blast-furnace Slag* (p. 25) is a very uncertain material as a coarse aggregate. Some slags readily disintegrate and are quite unsuitable, whilst others are inert and are commonly used locally in producing concrete of good quality. This is also referred to as " ballast " in districts where it is used (see also (*g*)).

Burnt Ballast is produced by burning clay in a kiln, and the slabs are then crushed and screened. It is a suitable material for coarse aggregate, provided it has been hard-burnt. Under-burnt ballast and that containing sulphur (from the fuel) should not be used.

(e) *Pumice* is a whitish or yellowish material of volcanic origin which is highly honeycombed. It was imported into this country, chiefly from Germany, and used as an aggregate for *lightweight concrete*. This concrete, although relatively weak, is, as its name implies, light and very suitable for partitions (pp. 45-47, Vol. III), covering flat roofs, encasing beams and pillars, and similar purposes where strength is not important. Pumice is crushed. Dust and shaly fragments should be removed. It does not contain sulphur and is inert.

(f) *Breeze and Clinker* are waste materials resulting from the burning of coal. Breeze is obtained from gasworks and coke ovens ; clinker is the mineral matter or ash from furnaces. These materials produced from certain coals, especially when they contain small particles of the coal, are distinctly unsound and should be avoided. They have been responsible for a large number of concrete failures owing to the considerable expansion which takes place when associated with cement. They may also have a large sulphur content, which will cause rapid and extensive corrosion of steel and the spalling off of the concrete. The Recommendations for a Code of Practice for the Use of Reinforced Concrete in Buildings classified these as " prohibited aggregates," and they must not therefore be used for reinforced concrete work or for encasing beams, pillars, etc. However, not all breeze and clinker are dangerous, and on account of their cheapness and lightness, much of it is used for internal concrete block or slab partitions (pp. 45-47, Vol. III).

(g) *Foamed Slag*, which somewhat resembles pumice, is produced from blast-furnace slag by rapidly cooling the molten material with water. It is light in weight owing to its cellular structure and is crushed and graded as required. It is very suitable for the manufacture of partition slabs (pp. 45-47, Vol. III).

(h) *Expanded Slate* is another good lightweight aggregate which has not been extensively used, probably because its cost is higher than that of foamed slag. It is produced by heating waste slate to a high temperature until its thickness is considerably increased. This light honeycombed material is then crushed and graded.

GRADING OF AGGREGATES.—The importance of suitably grading the aggregates in order to obtain a concrete of good quality has been referred to on p. 28. It is therefore desirable that samples of the aggregate should be taken periodically and examined.

These samples should be representative, and therefore several are taken from different parts of the consignment. These are well mixed together and a final test sample obtained. According to the Recommendations for a Code of Practice for the Use of Reinforced Concrete in Buildings,[1] this sample should weigh at least 3-lb. for fine aggregate, 10-lb. for coarse aggregate and 15-lb. where fine and coarse aggregates are to be combined. The sample is then passed successively through a series of nine standard sieves, *i.e.*, $1\frac{1}{2}$-in., $\frac{3}{4}$-in., $\frac{3}{8}$-in., $\frac{3}{16}$-in., No. 7 (0·0949-in. square mesh), No. 14 (0·0474-in. mesh), No. 25 (0·0236-in. mesh), No. 52 (0·0116-in. mesh) and No. 100 (0·0060-in. mesh). It will be observed that the size of opening of a sieve is double (or approximately so) that of the next smaller sieve. The aggregate retained on each sieve is then carefully weighed and the amount passed through each is expressed as a percentage.

The following figures shown in brackets are the approximate limits of material passing through the sieves in respect to fine aggregate suggested in the Report of the Building Research Board for 1936 : $\frac{3}{16}$-in. sieve (100 per cent.), No. 7 sieve (75 to 85 per cent.), No. 14 sieve (50 to 70 per cent.), No. 52 (30 to 55 per cent.) and No. 100 sieve (0 to 3 per cent.).

The following are the suggested limits of material passing through sieves in respect to coarse aggregate of a specified size varying from a maximum of $1\frac{1}{2}$-in. to a minimum of $\frac{3}{16}$-in. ; $1\frac{1}{2}$-in. sieve (95 to 100 per cent.) $\frac{3}{4}$-in. sieve (35 to 70 per cent.), $\frac{3}{8}$-in. sieve (10 to 30 per cent.) and $\frac{3}{16}$-in. sieve (0 to 5 per cent.) ; for $\frac{3}{4}$-$\frac{3}{16}$-in. coarse aggregate, the suggested limits are : $\frac{3}{4}$-in. sieve (90 to 100 per cent.), $\frac{3}{8}$-in. sieve (20 to 55 per cent.) and $\frac{3}{16}$-in. sieve (0 to 10 per cent.).

An approximate guide for grading is as follows :—

Not more than one-quarter and not less than one-twentieth of the sand of $\frac{3}{16}$-in. maximum size should pass through a No. 52 sieve. Unsuitable grading of the sand is a frequent cause of defects in concrete, and the strength and workability of the concrete depend a good deal upon the percentage of sand which passes through a No. 52 sieve. Thus, an excess of this fine material necessitates the addition of an *excessive amount of water* during mixing and a *decrease in the strength* of concrete results, whilst a deficiency of fine material causes unworkability and harshness. The above Code requires that not more than 3 per cent. by weight of the sand shall pass through a No. 100 sieve. Fine dust must be excluded from the aggregate.

For coarse aggregate of $\frac{3}{4}$-in. maximum size, not more than two-thirds and not less than one-fifth should pass through a $\frac{3}{8}$-in. sieve.

The shape of the particles of aggregate influence the workability of the concrete. Thus, concrete with crushed aggregate having sharp edges will require more water than that made of rounded particles, and therefore the latter

[1] These Recommendations are embodied in the Report of the Reinforced Concrete Structures Committee of the Building Research Board, 1933.

makes a stronger concrete for a given workability and is preferred to angular particles. The particles should be compact and not flat and elongated.

PROPORTIONING CONCRETE.—The composition of concrete varies considerably, depending upon the specific requirements in respect to strength, durability, impermeability, workability and economy, in addition to the quality and characteristics of the materials. Thus, the proportions of materials for concrete required for a reinforced concrete beam will differ from those for a concrete non-load-bearing internal partition or for site concrete.

Great care should be taken to determine the correct proportions of the materials. That of cement should always be specified by weight. The former practice of specifying cement by volume has been discontinued, as the weight of a cubic foot of cement is not constant but varies according to its fineness and the manner in which it is filled, loosely or otherwise. The unit of weight of cement usually taken is that of a bag of cement as sold, *i.e.*, 1-cwt.

The fine and coarse aggregates may be expressed either by weight or by volume. Although the former may be more accurate, it is not often adopted in this country where it is the common practice to specify the aggregate in terms of volume (cubic feet). Hence a concrete mix is usually specified as consisting of 1-cwt. of cement to so many cubic feet of fine aggregate and so many cubic feet of coarse aggregate. Examples of this form appear in the Model Bye-laws (1939) and in the Code of Practice for the Use of Reinforced Concrete in Buildings (see p. 29). Thus, the Bye-laws stipulate that site concrete shall consist of not less than 112-lb. of cement to every $3\frac{1}{2}$-cub. ft. of fine aggregate and 7-cub. ft. of coarse aggregate. The Code gives tables in which the following four arbitrary mixes appear :—

Nominal Mix.	Cement.[1]	Fine Aggregate.	Coarse Aggregate.
	Cwt.	Cub. ft.	Cub. ft.
1 : 1 : 2	1	$1\frac{1}{4}$	$2\frac{1}{2}$
1 : 1·2 : 2·4	1	$1\frac{1}{2}$	3
1 : $1\frac{1}{2}$: 3	1	$1\frac{7}{8}$	$3\frac{3}{4}$
1 : 2 : 4	1	$2\frac{1}{2}$	5

Sometimes a mix is specified as consisting of 1-cwt. of cement to so many cubic feet of fine and coarse aggregates combined. Thus, the Model Bye-laws require that concrete for foundations shall be composed of not less than 112-lb. cement to every 15-cub. ft. of coarse and fine aggregates in combination.

The 1 : 2 : 4 mix given in the above table meets general requirements and is often adopted ; both it and the 1 : $1\frac{1}{2}$: 3 mix are usefully employed for reinforced concrete work. The 1 : 1 : 2 and 1 : 1·2 : 2·4 mixes, having a high cement content, are suitable for producing very strong and impermeable concretes. There are several variations to these mixes, depending upon the class of work required.

[1] The weight of cement varies from 80 to 90-lb. per cub. ft. (see p. 31). Therefore the volume of 1-cwt. of cement is approximately $1\frac{1}{4}$-cub. ft.

In practice, and during wet weather especially, it is difficult to obtain batches of concrete which are uniform when the fine aggregate is measured by volume. This is due to the increase in volume, known as *bulking*, of the sand which occurs when it is in a moist condition. Experiments show that 1-cub. ft. of dry sand will approximately increase to $1\frac{1}{8}$-cub. ft. if 3 per cent. of water is added to it, and therefore there is actually less aggregate in 1-cub. ft. of moist sand than in the same volume of dry sand. If the water content increases to 4 per cent., the volume will be increased by approximately $\frac{1}{4}$; as the moisture increases beyond this percentage, the bulking gradually decreases, and when the sand becomes submerged the volume of the inundated sand is the same as that when dry. The finer the sand, the greater the bulking. This bulking of moist sand should be allowed for ; it is customary to assume that the volume has increased by 20 per cent., and therefore this amount of sand is added to the proportion of fine aggregate when mixing.

It is obvious that this is only an approximate correction. In wet weather, sand which has been deposited on a site has a variable water content. When high-grade concrete is required, the actual bulking may be obtained in the following manner : The gauge box used for measuring the fine aggregate (see p. 34) is filled with the moist sand. This sand is dried, returned to the box, and after being levelled off at the top the reduced depth of the sand is measured. The percentage of bulking equals

$$\frac{\text{Depth of box} - \text{depth of dry aggregate}}{\text{Depth of dry aggregate}} \times 100.$$

This method is not readily applied in practice and is only resorted to when specially called for.

The bulking of sand does not present any practical difficulties when the mixes are proportioned by weight. Coarse aggregates are not normally subjected to the phenomenon of bulking.

WATER.—The water used for mixing concrete is required to produce a workable plastic mix, in addition to hydrating the cement. It must be clean and fresh. It is emphasized that the strength of concrete depends upon the quantity of water used in relation to the cement content, and *an excess of water, however slight*, reduces the strength of the concrete.

The following tests were carried out in the Building Laboratory of the Manchester College of Technology to demonstrate to students the marked effect that the water content has upon the compressive strength of concrete : Three different mixes of concrete were separately prepared. The materials in mix " A " were mixed dry in the proportion of 1 : 1 : 2. The cement used was normal Portland cement. The mix was divided and each half was separately mixed with water, one half having 30 per cent. more water added than the other. A 4-in. cube (see p. 32) was then made from each half of each batch and tested for compression strength at the end of twenty-eight days. Mixes " B " and " C " were dealt with in a similar manner, the excess water added to one-half of each mix being also 30 per cent. The following were the results :—

TABLE I

Mix.	Proportions.	Normal Mixes.			Mixes with 30 per Cent. Excess Water.			Per Cent. Reduction in Strength.
		$\frac{W}{C}$.	Slump.	Strength.	$\frac{W}{C}$.	Slump.	Strength.	
			In.	Lb. per sq. in.		In.	Lb. per sq. in.	
A	1 : 1 : 2	0·43	2½	5,060	0·56	9	3,400	33
B	1 : 2 : 4	0·62	3½	2,940	0·81	9	1,690	42½
C	1 : 3 : 6	0·85	2	1,550	1·10	7	860	44½

These figures illustrate the appreciable reduction in strength as a result of excess water content.

This relationship between the quantity of mixing water and amount of cement in a concrete mix is known as the *water-cement ratio*, expressed as $\frac{\text{"W"}}{\text{"C"}}$ $\left(\frac{\text{Water}}{\text{Cement}}\right)$ either by volume, or by weight, or by the number of gallons of water per hundredweight (weight of a bag) of cement. Thus, if expressed by volume, 1-cub. ft. of water per 1-cub. ft. of cement equals a ratio of $\frac{1}{1}=1$; if by weight, this ratio becomes

$$\frac{62\cdot5\text{-lb. (weight of 1-cub. ft. of water)}}{90\text{-lb. (weight of 1-cub. ft. of cement)}^{1}}=0\cdot69\ ;$$

if 6-gals. of water are used per hundredweight of cement, the ratio is

$$\frac{6\times10\text{-lb. (weight of 1-gal. of water)}}{112}=0\cdot54.$$

Whilst in the laboratory the materials are usually taken by weight, it is more convenient for practical purposes to specify the number of gallons per hundredweight bag of cement. The $\frac{W}{C}$ ratios and the corresponding strengths shown in Table I clearly indicate that the strength of the concrete is lowered as a result of the additional water.

It is not possible to state definitely the amount of water which should be used in a concrete mix, as this depends upon the desired workability, amount of water in the fine aggregate and that absorbed by the coarse aggregate. An approximate rule for finding the amount of water for concrete consisting of dry and non-porous aggregate is to take 28 per cent. of the weight of the cement plus 4 per cent. of the weight of the aggregate. Thus, for a 1 : 2 : 4 mix requiring 1-cwt. cement, 2½-cub. ft. sand (weighing 100-lb. per cub. ft.) and 5-cub. ft. gravel (weighing 98-lb. per cub. ft.), the number of gallons of water equals :

(Cement) $\frac{28}{100}\times1\times112=31\cdot36$ lb. $\div10=3\cdot14$ gals.

(Sand) $\frac{4}{100}\times2\frac{1}{2}\times100=10\cdot00$ „ $\div10=1\cdot00$ „

(Gravel) $\frac{4}{100}\times5\times98=19\cdot60$ „ $\div10=1\cdot96$ „

6·10 gals.

SLUMP TEST.—The best practical test for determining the desired workability of concrete and the required amount of water is that known as the slump test. This is now universally adopted both on the site during the progress of the work and in the laboratory. The apparatus simply consists of a metal mould, frustum of a cone in shape, with both ends open and provided with two handles ; the dimensions are 12-in. high, 8-in. internal diameter at the bottom and 4-in. internal diameter at the top (see G, Fig. 9). A 2-ft. long metal rod, $\frac{5}{8}$-in. in diameter and bullet nosed, is also required.

In carrying out the test, the mould is placed on a flat surface which *must be non-absorbent*. It is filled with the freshly mixed concrete to a height of about 3-in. ; this is puddled to expel the air by applying twenty-five strokes of the rod. The filling is completed in similar successive consolidated layers and the surface is struck off flush with the top by a trowel. The mould must be held firmly as it is being filled, and to prevent movement it may be provided with two flat footpieces, attached near the base, upon which the operator stands. Immediately it is full, the mould is carefully lifted *vertically* and placed on the mixing surface adjacent to the concrete specimen, which will have subsided or slumped. The amount of settlement, which varies according to the water content, is measured in inches by placing a rule across the top of the mould and measuring the height that its lower edge is above the top of the concrete. Thus, at H, Fig. 9, a 3-in. slump is indicated.

This is an excellent practical test, as it is simple and takes little time to carry out on the job. By its use it is possible to reasonably control and obtain a uniform consistency of the concrete. It is important to note that the slump will be affected if the cement and aggregates are changed, and therefore any such change of materials will necessitate preliminary trial tests to see if any alteration in the slump is necessary. A slump test is taken daily to check the consistency (or condition of wetness) of the concrete used for first-class work.

[1] The weight of 1-cub. ft. of cement depends upon its fineness; thus, for normal Portland cement the weight is usually taken as 90-lb per cub. ft.; the finer ground rapid-hardening Portland cement may only weigh 80-lb. per cub. ft.

The slump values vary with different classes of work and the following may be taken as a general guide: For mass concrete and heavy reinforced concrete structures the slump varies from 1 to 4-in. It may be necessary to increase the slump to 7-in. for columns, and for thin vertical and confined horizontal structures where adequate ramming of the concrete is not possible. For concrete roads the maximum slump should not exceed 1-in. in order that the necessary strength and wearing qualities may be obtained. Whilst a 7-in. slump is considered as a maximum for good quality mixes, it may be possible to increase this figure to 8-in. for concrete which does not require a high standard of strength. Concrete having a slump less than 2-in. must be well consolidated when placed in position to avoid honeycombing or pore spaces (see p. 35).

COMPACTING FACTOR TEST.—This is another test applied to concrete, but it is only suitable for use in the laboratory. It is related to the workability of concrete, which is defined for this purpose as being the property which determines the amount of work required to compact or consolidate the concrete completely. The compacting factor may be defined as a measure of the density of a concrete achieved by a standard amount of work.

The apparatus used for this test consists of a frame which supports two truncated conical hoppers, one above the other, with a space between. A cylindrical mould, having a detachable base, is placed below these hoppers. Each of the latter has a hinged base which can be shot open.

The upper hopper is completely filled with the concrete immediately after mixing. The hinged door is released to allow the contents to fall into the lower hopper. The base of the latter is then opened and the concrete falls into the cylinder, completely filling it, the excess concrete being struck off level with the top. The compacting factor is then calculated in the following manner: The weight of the container when empty is subtracted from that of the container when full, and this net weight of concrete is divided by the weight of the concrete calculated from the known specific gravities of the cement, sand and coarse aggregate, in the correct proportions, required to fill the cylinder without pore spaces. Thus, if the net weight of the concrete is 125·5 oz. and that of the contents of the cylinder (when no voids are left) is 133·8 oz., the compacting factor will be $\frac{125{\cdot}5}{133{\cdot}8} = 0{\cdot}94$. Experiments have shown that a compacting factor of 0·95 represents a concrete mix of high workability, that of 0·92 a medium workability, and 0·85 a low workability.

This is a useful test for comparing the workability of different mixes of concrete. Each specimen is brought to a standard condition (when deposited from the upper to the lower hopper) and is subjected to a standard amount of work when it falls into the cylinder.

COMPRESSION TEST.—The quality of concrete is generally assessed by its crushing strength. This strength is determined by testing suitably prepared specimens of the concrete in a compression machine.

The form of standard test specimen favoured in this country is the 6-in. cube. This and the standard method of testing are specified in the Code of Practice referred to on p. 29. The cement and fine aggregate, in correct proportions, are first mixed dry until a uniformly coloured mixture is obtained; the coarse aggregate is added and well mixed; the correct amount of water is then added and the composition mixed for at least two minutes. The concrete is tested for consistency by the slump test, described on p. 31. and after re-mixing it is placed in a steel mould of 6-in. by 6-in. by 6-in. internal dimensions. The mould has a steel base plate attached, and both this and the internal faces of the mould must be well oiled before filling to make the joint watertight, prevent sticking of the concrete and facilitate the removal of the cube without damage. The concrete is placed in the mould in three layers of approximately equal thickness, each layer being separately tamped 35 times if the slump is 1½-in. or less (or 25 strokes for wetter mixes) with a 15-in. by 1-in. by 1-in. steel bar weighing 4-lb., after which the surface is carefully smoothed level with a trowel flush with the top of the mould. The mould is then stored in a damp cabinet for twenty-four hours, after which the concrete cube is removed from the mould, marked, and either immersed in water contained in a tank or buried in damp sand until the cube is ready for testing. This protection of the cube, called *curing*, is necessary to prevent evaporation of the water and to provide a favourable condition for the setting and hardening of the concrete. The strength of the concrete is usually taken at either fourteen or twenty-eight days after it has been mixed; occasionally early date strengths are taken at three and seven days, and sometimes the strengths at three months and one year are required.

Test cubes prepared on the site during the progress of the work are kept damp for twenty-four hours and then removed from their moulds. After being marked to distinguish them, they are carefully packed in a wood box, encased in damp sand or sacking and dispatched to the laboratory where they are kept damp until required for testing.

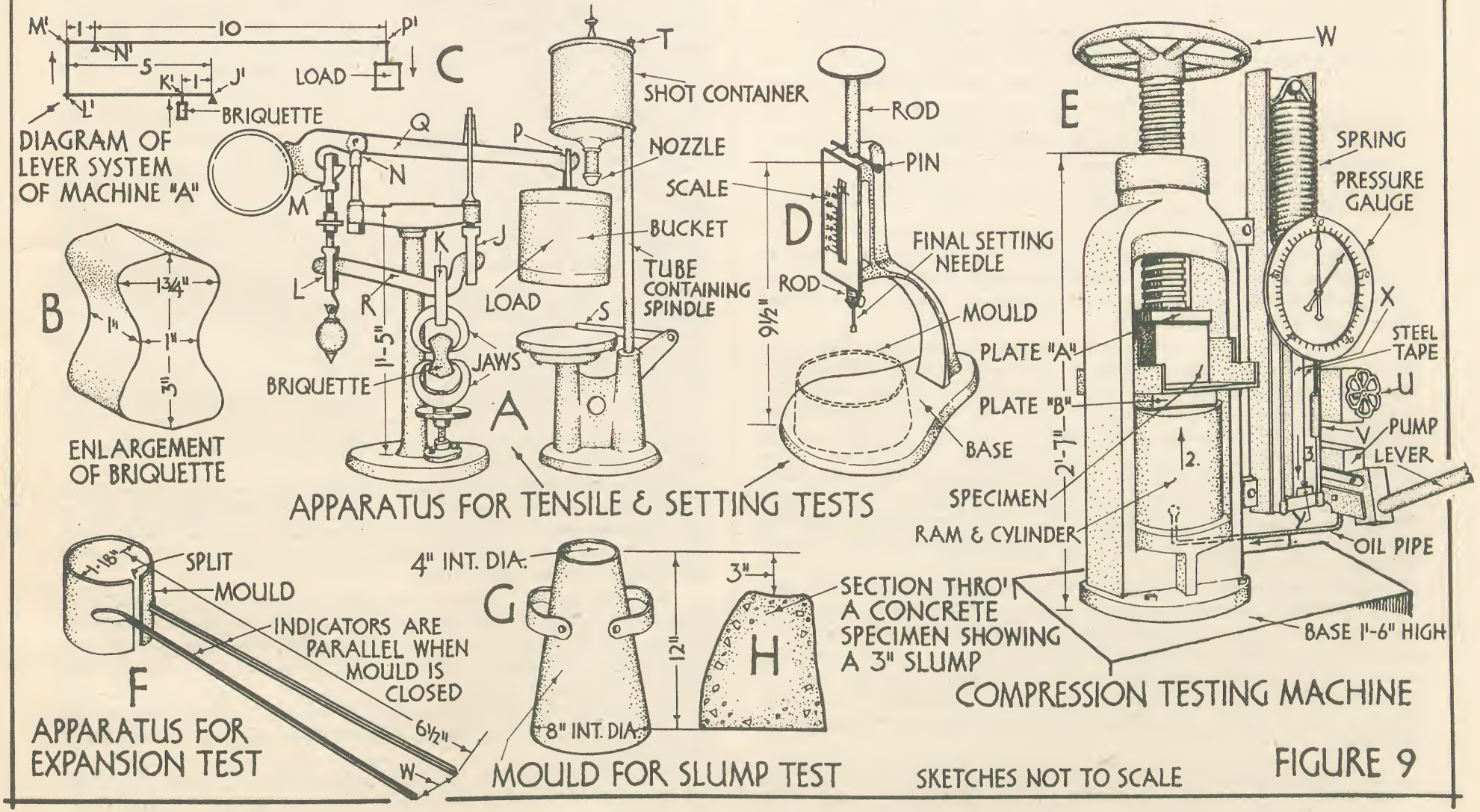
One type of compression testing machine, manufactured by Messrs J. A. Amsler, and of 50-tons capacity, is shown at E, Fig. 9. The concrete specimen is placed on the lower compression plate B attached to the ram or piston which operates within the press cylinder. The upper compression plate A is connected by means of a ball-and-socket joint to the large screw which is operated by the hand wheel W. The screw is adjusted to lower the plate A tightly on to the top of the specimen. Brackets at the right-hand side support the oil pump, subsidiary cylinder X with small piston, pressure gauge and spiral spring. Oil is conveyed by a pipe to the pump from a reservoir fixed to the back of the machine; the pump is connected to the press cylinder by an oil pipe, and a branch (not shown) from this pipe is connected to the subsidiary cylinder X.

After plate A has been tightened down and valve U closed, the pump is operated by raising and lowering the 3-ft. long lever by hand. This forces the oil along the pipe (see arrow "1") into the press cylinder to exert pressure on the underside of the ram. The latter and plate B gradually rise (see arrow "2") to press the specimen against the stationary plate A. Meanwhile the oil forced along the branch pipe to cylinder X presses the piston downwards (see arrow "3") and this extends the spiral spring. This extension of the spring is transmitted to the indicating hand or pointer on the gauge by a steel ribbon tape which is fixed at Y and passed round a pulley fixed to the spindle of the pointer and weighted at V. This causes the pointer to rotate round the dial, the scale on which is calibrated to give direct load readings. The pump is operated and the oil pressure increased, until the specimen is crushed. When this occurs the indicating hand gradually returns to zero, but a loose pointer, which the hand engages as it rotates during the test, remains to register the highest point reached when the specimen failed. This figure, expressed in tons, is converted to pounds and divided by the area of the cross-section of the specimen to give the crushing strength of the concrete in pounds per square inch. The specimen is removed by opening valve U and reversing the hand wheel W; this relieves the pressure on the press cylinder and the weight of the ram forces the oil from the cylinder to the reservoir.

Very little effort is required to hand-operate this machine and the time taken to carry out the test is approximately two minutes, depending upon the strength of the cube (about 1-ton per sq. in. per min.).

For testing specimens requiring comparatively small pressures to crush them (such as timber), the spring on the 50-ton machine is replaced by a lighter one and the dial is substituted by one reading to 20-tons. This type of machine is also made having a capacity of 200-tons. This larger machine is necessary when 6-in. concrete cubes have to be tested, as a 50-ton machine will only test 4-in. cubes at twenty-eight days.

TESTING APPARATUS FOR CEMENT ETC.



The specimens referred to in Table I, p. 31, were tested in a 50-ton machine. The following results of tests, which may be considered as typical, show how the strength of concrete, having a 2-in. slump, increases with age :—

TABLE II

Type of Cement.	Nominal Mix.	Compressive Strength (Lb. per Sq. In.).				
		3 Days.	7 Days.	28 Days.	3 Months.	1 Year.
Ordinary Portland .	1 : 2 : 4	1,400	2,500	3,900	4,800	6,500
Rapid-hardening P. .	1 : 2 : 4	2,500	3,500	5,000	5,500	7,000
High Alumina .. .	1 : 2 : 4	7,000	7,300	8,000	No appreciable increase	

MIXING CONCRETE.—It is most important that the materials shall be thoroughly mixed in correct proportion. The mixing should be continued until the concrete is of a uniform colour and consistency. Concrete is either (1) hand-mixed or (2) machine-mixed.

1. *Hand-mixing*.—This method is still adopted on small jobs. The mixing should never be carried out on the bare ground, as this results in the materials being contaminated by the earth which is scraped up. It should be done on a proper close-boarded platform or staging, 9 or 10-ft. square, preferably made of t. and g. floor boards fixed to five lengths of 4-in. by 2-in. battens. The joints of the boards must be close to prevent the escape of liquid grout. Sometimes the boards are protected by a covering of sheet iron or zinc plate, and a raised kerb round three of the sides is provided. The platform should be quite level to prevent the water from draining off, and it should be placed conveniently near to the place at which the concrete is to be deposited. A water point is brought near to the platform.

Careful measurement (or weighing) of the materials is essential for good quality concrete. It should be done in relatively small quantities, and a convenient form of measure for the sand and coarse aggregate is a square or rectangular box or frame, similar to the batch box H, Fig. 23 ; it is without a base. This measuring frame should not be too large as to become unwieldy to handle conveniently ; one of 1-cub. ft. capacity is often preferred. A wheelbarrow, of known capacity when filled level with the edges, is also used instead of a frame.

If a 1 : 2 : 4 composition (requiring 1-cwt. bag of cement, 2½-cub. ft. of sand and 5 cub. ft. of broken stone, p. 30) is specified, a convenient size of mix would be 5-cub. ft. of sand, 10-cub. ft. of broken stone to 2 bags of cement, and the internal dimensions of the frame would be as indicated at H, Fig. 23.[1] This is preferred to a large frame which would be filled to the level of a mark which becomes obliterated in course of time.

The measuring frame is placed on and near to one end of the platform, filled to the top with the coarse aggregate, and then lifted. If the frame is of 2½-cub. ft. capacity, it is laid on the platform near the heap already formed, again filled with coarse aggregate and removed. This is repeated until four frames of coarse aggregate have been measured ; after it has been levelled off, two bags of cement are emptied and evenly distributed over the coarse aggregate. The measuring frame is placed on the heap and filled level to the top with sand and removed ; this is repeated to give two frames of sand. Some prefer to add the sand after two frames of coarse aggregate have been measured ; the remaining two frames of coarse aggregate are then added, followed with the cement.

The materials are then mixed at least " twice dry and twice wet." Usually two men, one on each side of the heap, shovel the heap to one side, turning and sprinkling the materials in the process. This operation is repeated, the heap being thrown back to its original position. If necessary the materials are again turned over until the colour is uniform, free from streaks of brown and grey. Water is then added. Only the correct amount of water (varying with the nature of the work and materials, and probably determined from a slump test (see p. 31), must be used. It may be measured by a bucket of known capacity, probably 2½-gals. The water should not be thrown on to the heap from the bucket, as this washes the cement from the aggregate, but rather sprinkled on by means of a watering-can, having a rosehead, and which is filled from the measured pails. Usually a third man adds the water whilst the other two attend to the mixing and turn over the heap at least twice, as above described, until a uniform consistency is obtained.

An alternative method of mixing is to spread the measured sand in a layer of even thickness on the platform, the cement is distributed over this, both are mixed together until the colour is uniform, the coarse aggregate is thrown over the mixture which is turned over at least twice. Water is added and the whole again turned over two or three times.

2. *Machine-mixing*.—Concrete is now chiefly produced by mechanical mixing except where only small quantities are required. Machine-mixing is faster and cheaper than hand-mixing, and it generally produces a more thorough mix having additional strength.[1] There are two groups of mixers, *i.e.*, (*a*) batch mixers and (*b*) continuous mixers.

(a) *Batch Mixers*, which are portable, include the (i) tilting drum and (ii) closed drum types. Each is usually driven by either a petrol or oil engine or an electric motor.

(i) The *tilting drum mixer* (see line diagram J, Fig. 23) consists of a hopper and mixing drum. Correct quantities of cement and aggregates are loaded into

[1] The concrete must be mixed and deposited as quickly as possible, and the size of the mix should therefore depend upon the amount of labour available.

[1] In the Code of Practice for Reinforced Concrete (see p. 29) it is recommended that concrete should be mechanically mixed ; if mixed by hand an additional 10 per cent. of cement should be used.

the hopper, which is raised to discharge the materials into the drum. A convenient size of wood *batch box*[1] for the aggregate (if 2½-cub. ft. of sand and 5-cub. ft. of coarse aggregate are used) is shown at H, Fig. 23, the box being twice filled for the coarse aggregate. The coarse aggregate is first placed in the hopper, followed by the sand and the cement. The capacity of the drum varies considerably, one of 10/7-cub. ft. being useful for average work ; the first number indicating the capacity (in cubic feet) of unmixed materials and the latter number that of the wet concrete produced. The correct amount of mixing water is discharged into the drum from an automatic tank fixed above it. Projecting metal baffle blades fixed to the inside of the drum assist in the distribution of the materials as they impinge against them whilst the drum is revolving. The period of mixing, which may be controlled automatically, should not be less than one minute and not more than two minutes after all of the materials have been added. The strength of the concrete is not materially increased if the latter period is prolonged ; excessive mixing produces an undesirable stiffening up of the concrete. When mixing has been completed, the drum is stopped and rotated vertically to discharge the concrete.

(ii) The *closed drum mixer* has a hopper, a mixing drum which rotates on a horizontal axis, and a steel chute which is inserted into the drum after the mixing has been completed and down which the concrete is discharged.

(b) *Continuous Mixers.*—These are used on large engineering jobs. The aggregate, cement and water are mechanically measured and fed into the mixer from which the concrete is continuously discharged.

CENTRAL MIXING.—In connection with large contracts, a central batching and mixing plant is often installed on the site. This may consist of large elevated storage bins, below which are hoppers and mixing drums. The aggregate is conveyed to the storage bins and these feed the measuring hoppers below as required ; the hoppers also receive the cement. The materials from the hoppers pass into the mixing drums, water is automatically added, and, after being mixed, the concrete is deposited into trucks and transported on rails to the required part of the site, where it is deposited.

Central batching plants are now being used to batch the materials and discharge them into mixing trucks which perform the actual mixing in course of transit from the plant to the job.

PLACING CONCRETE.—Concrete should be placed in position as soon as possible and within half an hour of mixing. For short distances the concrete is usually shovelled from the mixing platform or discharged from the mixing drum into watertight steel wheelbarrows or handcarts, often pneumatically tyred to reduce vibration, and conveyed to the place of deposition. In order that the effect of the mixing will not be nullified, concrete must be carefully placed and not thrown from a height, otherwise its consistence becomes non-uniform by the separation of the heavier from the lighter particles. Concrete required for upper floors is hoisted by means of a *barrow-lift* (pulley block and tackle, attached to the scaffolding, for lifting the full barrows) or *concrete-hoist* (large hoppers containing the concrete are lifted to any desired height, the apparatus resembling the ordinary passenger-lift).

[1] *This box is sometimes provided with a base.*

The placing of concrete on a large scale may also be effected either by tipping-trucks, towers or by pumping. Tipping-trucks, as already explained, run upon rails laid round the site and convey the concrete where required. A tower may reach a great height ; a mechanical mixer is placed at the bottom, and this feeds concrete into large receptacles which are hoisted to the top of the tower where the concrete is passed down inclined shoots and deposited where required. Pumping concrete has been proved effective on large jobs where congested conditions prevent the placing of the mixer on the site ; a pump forces the mixed concrete through a steel pipe, 4 to 6-in. in diameter, to the place of deposition ; concrete has been delivered in this manner to a height exceeding 100-ft. and for a horizontal distance of approximately 1,000-ft.

COMPACTING CONCRETE.—Concrete after being placed in position should be well *rammed* or *punned* or *tamped* to consolidate it. This is done either by hand or mechanically. Two forms of rammers are shown at F and G, Fig. 23 ; these may be used for mass concrete. Metal pummels, similar to G, of various sizes are employed for consolidating the concrete round the steel bars in reinforced concrete structures. For mass concrete work the concrete is laid in layers not exceeding 12-in. thick, and each layer must be compacted before the next is spread. For reinforced work the concrete should be deposited in successive layers not exceeding 6-in. in thickness, and these must be rammed in turn. A ⅝-in. rod is useful for ramming (or " rodding ") concrete and expelling the air (see also p. 31).

For concrete work on a large scale, hand-compacting methods are being replaced by mechanical means. The concrete is consolidated by vibration, the *vibrators* being operated by compressed air or electricity. One form, called a *surface vibrator*, consists of a flat plate which is placed on the surface of the concrete, a vibrating appliance is attached, and this transmits rapid shocks or vibrations to the concrete which is consolidated as the plate is moved slowly over the surface. Another form of vibrator consists of a single needle, 2½-ft. long (or a fork with four prongs), which penetrates the concrete as the appliance, held by both hands at the head, vibrates and consolidates. *External vibrators* are adopted for vibrating reinforced concrete work. The vibrators are clamped to the formwork (temporary wood framing used to support the concrete until it hardens). These transmit shocks (some 9,000 per minute) through the formwork to the concrete and consolidation results.

Vibrated concrete is denser than that which is hand-compacted, and it is therefore more impervious and weather-resistant.

CURING CONCRETE.—The water must not be allowed to evaporate from the concrete, and the longer the concrete is kept moist, the more effective will be the chemical combination of the cement with the water. The rapid drying out of the water considerably reduces the strength of the concrete. The concrete should therefore be covered over immediately it has been consolidated. A layer of sand or sacking, upon which water is sprinkled each day for a week, is effective. Surface bituminous coatings are sometimes applied to prevent evaporation, the liquid being sprayed on the concrete.

Frost can do considerable damage to concrete before it has hardened, and

once it has frozen it does not increase in strength. As a protection against frost, the concrete should be at once covered over with sacks, tarpaulins, straw, sawdust, etc. Canvas screens assist in protecting concrete from cold winds, and in severe weather the covering of windows affords a partial protection to internal concrete work in buildings in course of construction.

WATERPROOFED CONCRETE.—The production in a laboratory of concrete which is practically waterproof is a relatively simple matter when clean, well graded and best quality materials, properly proportioned, are thoroughly mixed with the correct amount of water under ideal conditions. In practice, however, where the conditions are less favourable, impervious concrete is not readily produced, and unless the various factors which tend to the production of good quality concrete are rigidly controlled, it will be interspersed with voids to such an extent as to render the product porous. Where the concrete is required to be impervious, it is now a common practice to use admixtures, known as waterproofers, which will have the effect of reducing the void space. Reference has been made to waterproofers on p. 27. The powder, paste and liquid forms are used for waterproofing concrete. The amount of waterproofer added to the concrete varies, but if in powdered form the usual proportion is 3-lb. of the powder to 100-lb. of cement. When hand-mixed, the concrete is prepared by adding the required amount of the waterproofer to the cement and thoroughly mixing them. This is then added to the aggregate as explained on p. 34. If the concrete is machine-mixed, it is recommended that approximately half of the coarse aggregate, sand and cement are charged in this sequence into the hopper, all of the waterproofer is then spread over the cement, followed by the rest of the cement, sand and aggregate ; these are placed into the drum, which is rotated for about one-quarter of a minute before the measured amount of water is added and the mixing is completed. The general proportion of paste waterproofer is 3-lb. of paste per 100-lb. of cement, the paste being dissolved in the mixing water before the latter is added to the cement, sand and coarse aggregate. When in liquid form, the waterproofer is usually in the proportion of 1-gal. of the liquid to 15-gals. of the mixing water (see pp. 27 and 57).

Certain of the waterproofers are just finely ground chalk, talc and iron filings which reduce the voids in the concrete. Others are chemically active, such as sulphate and sodium carbonate. Waterproofers which are claimed to act as water-repellents (impermeable materials which line the pores) include resin, calcium soap, and soda mixed with calcium chloride or lime.

BONDING

Students should revise the principles of English and Flemish bonding, which are stated on pp. 3 to 15, Vol. I.

SQUINT JUNCTIONS.—Most junctions between walls are right-angled, as described on p. 10, Vol. I, and squint or oblique junctions are not often called for.

Fig. 10 shows some typical examples of squint junctions. Those at A, B, C and D show English bond and the remainder are in double Flemish bond.

Details A and B show alternate courses of 9-in. and 13½-in. squint walls connected at an angle of 45° to a 13½-in. wall, and those at C and D indicate an angle of 60° between the walls. It should be noted in each case that (1) the heading course of the squint wall is bonded into the stretching course of the main wall, (2) the alternate stretching course of the squint wall butts against the heading course of the main wall and (3) the first brick at J in this stretching course is a three-quarter bevelled bat. For comparative purposes and convenience in setting-out, the angle between the walls in each detail has been made to coincide at J with the continuous transverse joint of the main wall. In practice, both the position and magnitude of this angle vary.

The double Flemish details at E to H show similar angles and thickness of walls. It will be observed that, for convenience, the 6¾-in. bevelled bat in each of the squint walls coincides with the through transverse joint of the main wall at J, and the first bonding brick in the alternate course of each squint wall is a header on face.

In this class of work the amount of cutting necessary to avoid continuous vertical joints should be kept to a minimum, the cut bricks should be as large as possible, and awkward shapes of bricks difficult to cut should be restricted.

SQUINT QUOINS.—The description of the more usual right-angled or square quoins on pp. 10 and 12, Vol. I, should be referred to when considering squint quoins. The latter are of two forms, *i.e.*, (*a*) obtuse and (*b*) acute squint quoins.

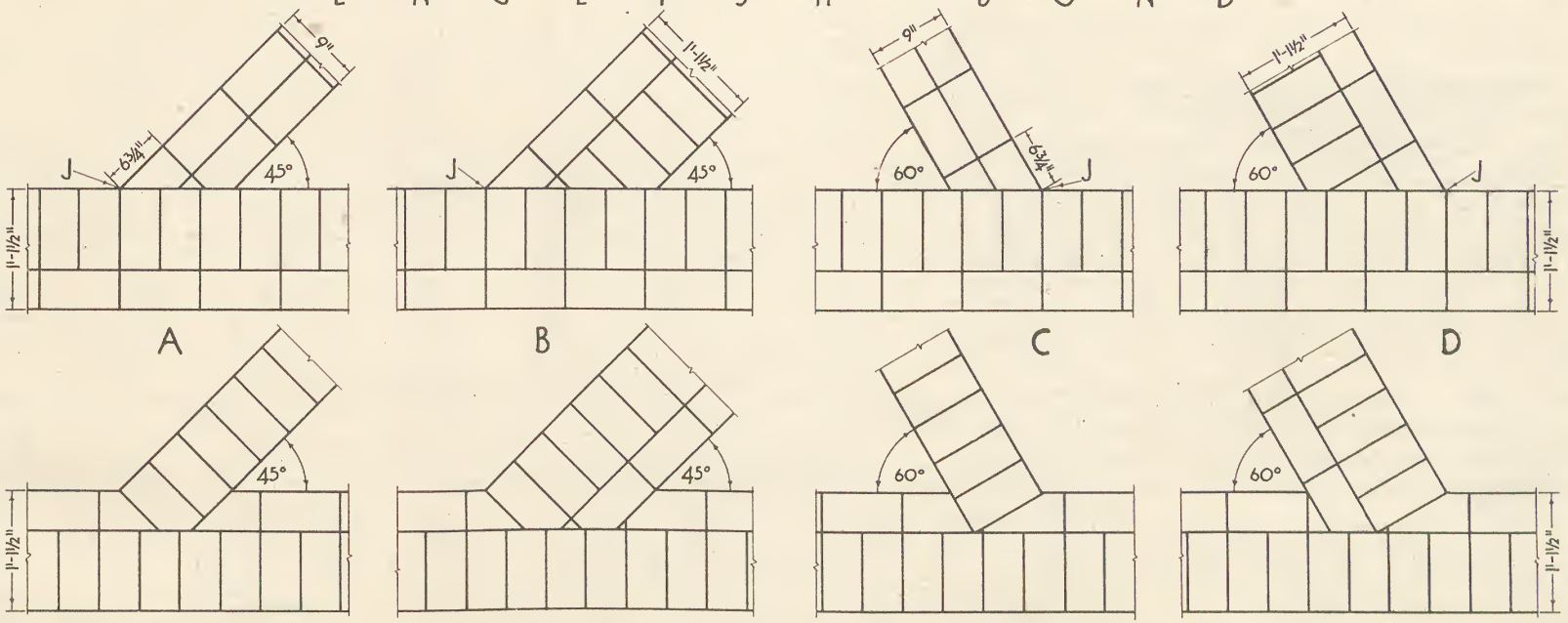
(a) *Obtuse Squint Quoins.*—These are formed when two walls meet at an internal angle greater than 90°, such as at a bay window (see O, Fig. 11) and splay-corners of buildings adjoining streets. Typical examples are shown at A, B, C, D and E. Conforming to the general rule, the closer appears next to the quoin header, which latter is often less than 4½-in. on face. It should be noted that, in each case, the combined width of the header and closer is 2¼-in. less than the quoin stretcher. Thus, the alternate courses at A show the stretcher face to be 6¾-in. ; therefore the return header, together with the closer, is 6¾-in. − 2¼-in. = 4½-in. ; as the header is 3-in., the closer is 4½-in. − 3-in. = 1½-in. as shown. Joints which appear at the internal angles should be lapped as much as possible at successive courses. In this connection stability would be increased at the internal angle at A if purpose-made bricks Q and R (shown shaded) were used, as these would eliminate the 4½-in. wide mitred joints at the angle.

For faced work it is now general to employ purpose-mades for the quoin bricks, and most of the larger manufacturers stock special bricks, such as A, B, C, D and J, Fig. 5, for this purpose. A much better appearance is thus obtained than when ordinary standard bricks are cut to shape. In the absence of purpose-made bricks, wire-cuts only should be shaped, as those with frogs produce ugly joints if the margins are removed.

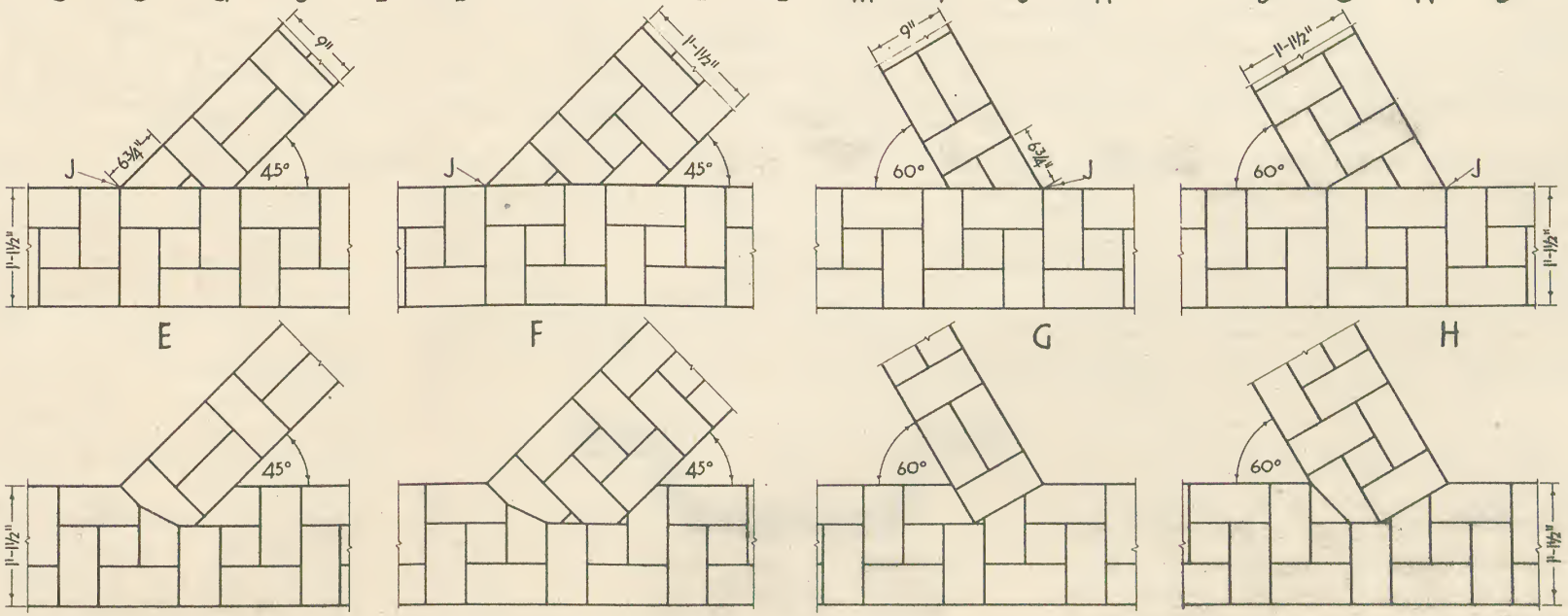
(b) *Acute Squint Quoins* are rarely employed. They are necessary at corners of

SQUINT JUNCTIONS

ENGLISH BOND



DOUBLE FLEMISH BOND



SEE FIG.5, VOL.1 FOR
RIGHT ANGLED JUNCTIONS

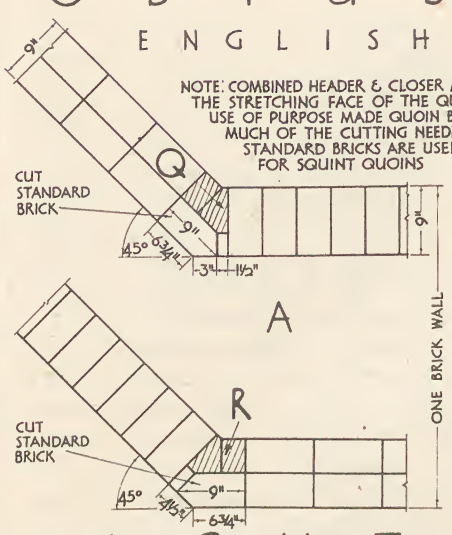
SCALE 0 1 2 FEET

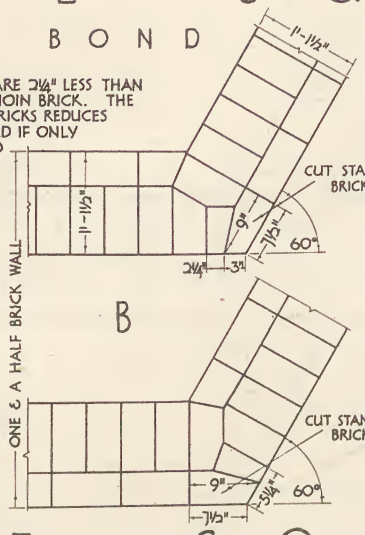
FIGURE 10

OBTUSE SQUINT QUOINS

ENGLISH BOND

NOTE: COMBINED HEADER & CLOSER ARE 2¼" LESS THAN THE STRETCHING FACE OF THE QUOIN BRICK. THE USE OF PURPOSE MADE QUOIN BRICKS REDUCES MUCH OF THE CUTTING NEEDED IF ONLY STANDARD BRICKS ARE USED FOR SQUINT QUOINS





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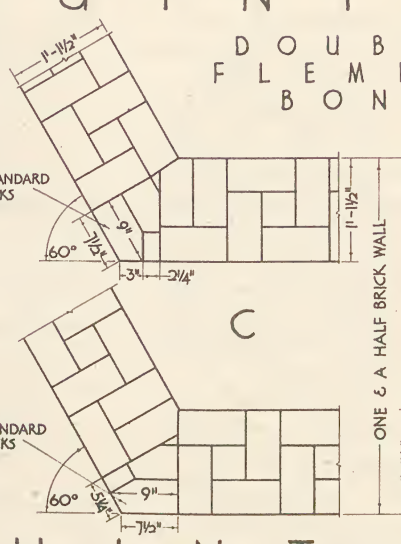
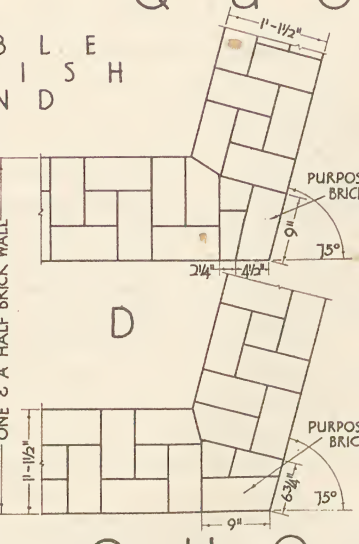
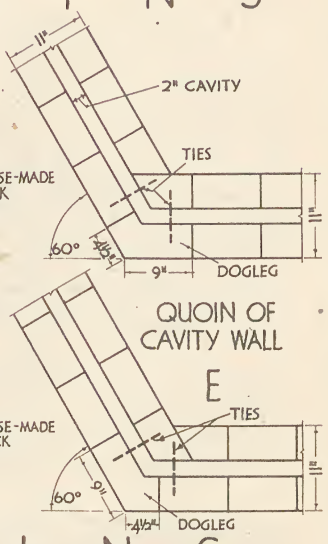
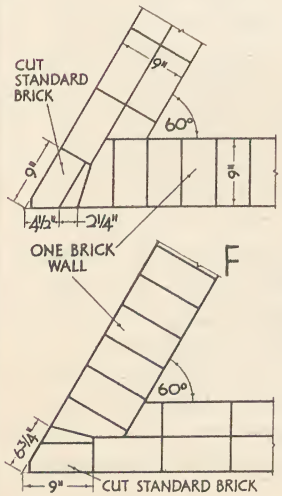


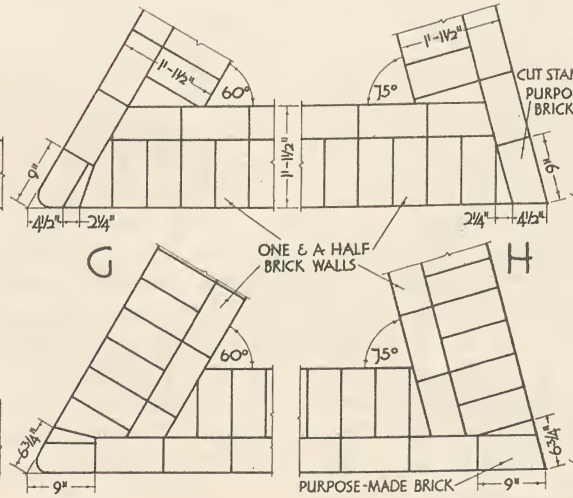


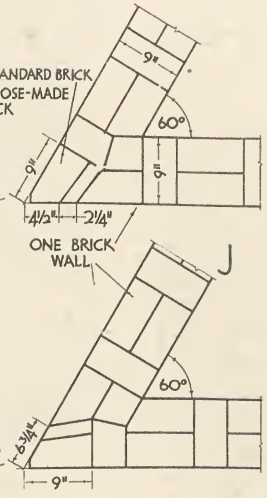


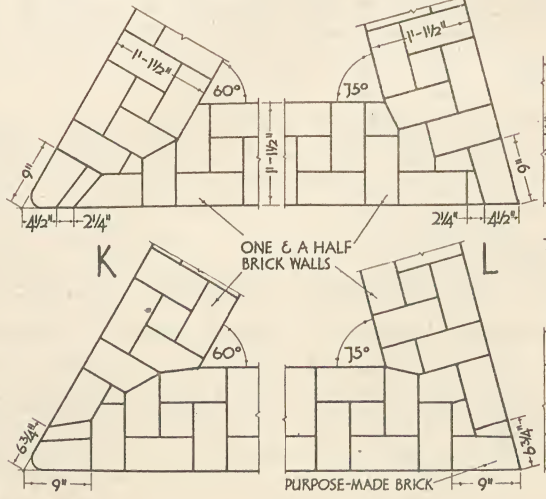
ACUTE SQUINT QUOINS

ENGLISH BOND

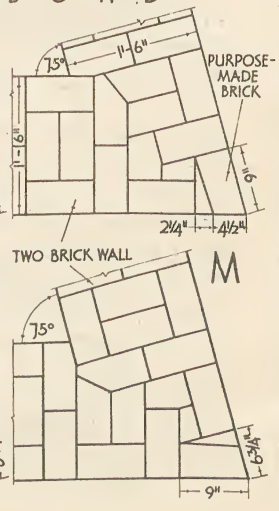


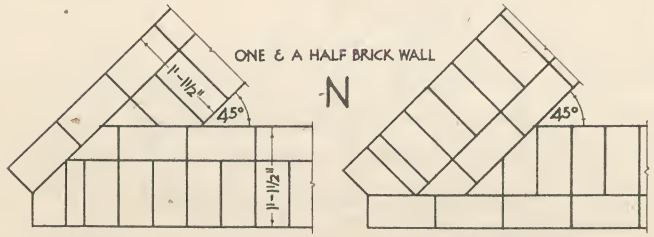






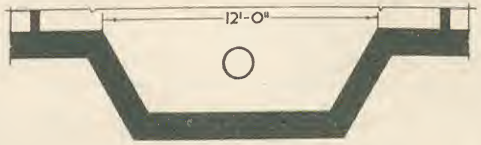
DOUBLE FLEMISH BOND



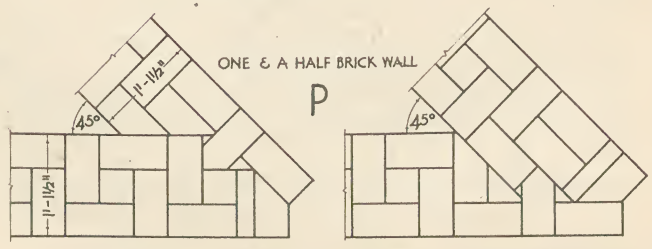


ALTERNATE COURSES SHOWING BIRDSMOUTHED ACUTE SQUINT QUOIN IN ENGLISH BOND

SEE FIG. 6, VOL. I FOR RIGHT ANGLED QUOINS



KEY PLAN OF BAY WINDOW SHOWING APPLICATION OF OBTUSE SQUINT QUOINS



ALTERNATE COURSES SHOWING BIRDSMOUTHED ACUTE SQUINT QUOIN IN DOUBLE FLEMISH BOND

FIGURE 11

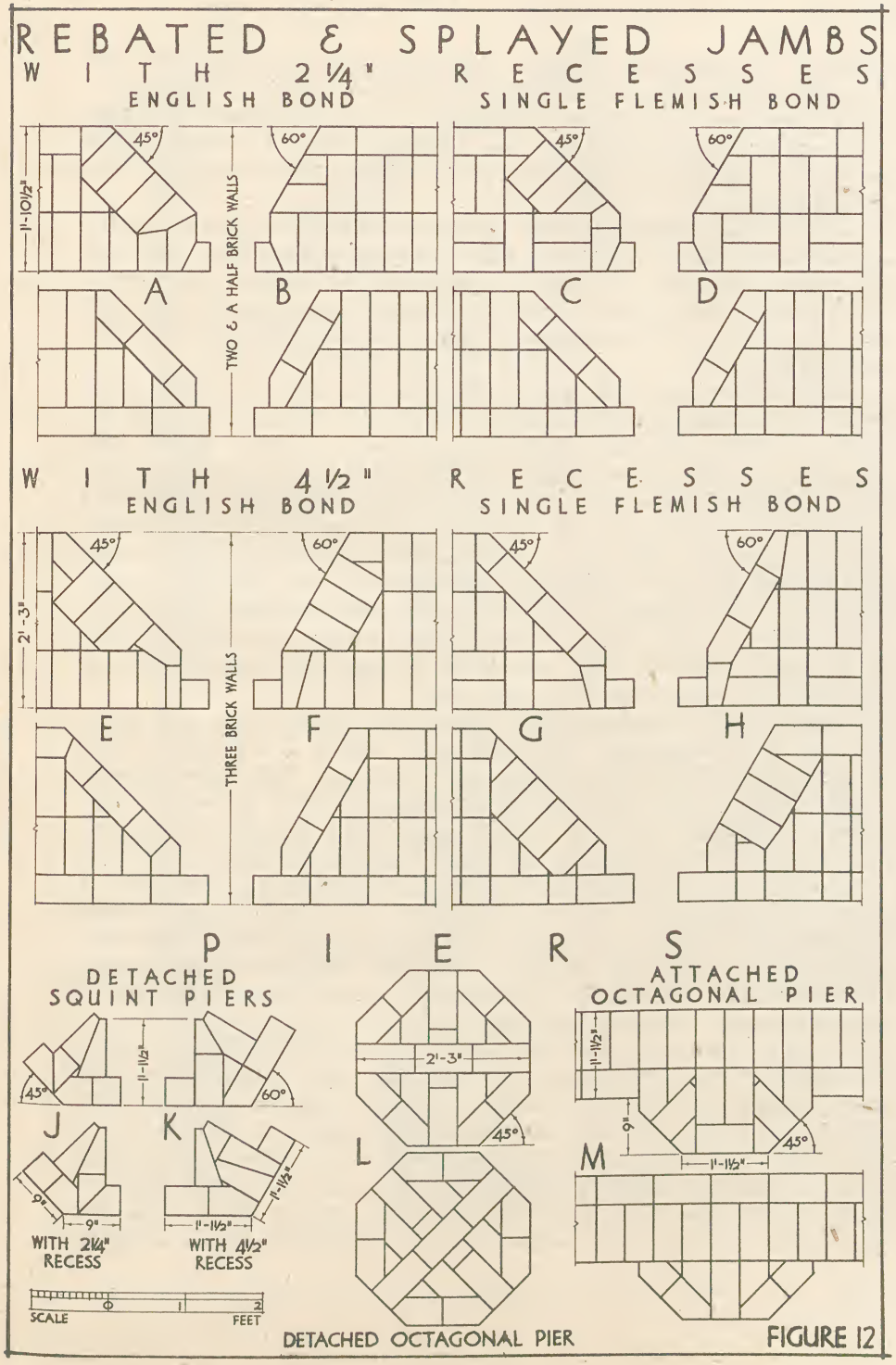


FIGURE 12

buildings abutting on streets which meet at an internal angle less than 90°. A few typical examples are detailed in Fig. 11, those at F, G, H and N showing alternate courses in English bond and those at J, K, L, M and P indicating alternate courses in double Flemish bond. In each case the rules of bonding which influence the face appearance have been complied with (see pp. 7 to 12, Vol. I).

Several expedients are sometimes adopted to dispense with the sharp arrises at very acute quoins, as such are readily damaged, difficult to cut (if standard bricks are used) and may cause injury to persons coming in contact with them. Thus, at F and J the corner is removed (or, preferably, purposely moulded to the shape shown) and bullnoses are shown at G and K. A simple and effective alternative is shown at N and P, where a bird's-mouthed appearance is obtained by the use of standard bricks which require little cutting and which cut surfaces are not exposed.

The above are only a few examples of squint quoins. There are a number of alternatives. The aim should be to obtain the maximum lap with the minimum of cutting. Whilst the correct face appearance is not necessary if the walls are to be plastered, the principles of sound bonding should be observed and continuous straight joints avoided.

Rebated and Splayed Jambs.—These are in addition to the square and rebated jambs described on p. 13, Vol. I, to which reference should be made.

Rebated and splayed jambs are detailed here in Fig. 12. As shown, such a jamb (if of a window opening) consists of a square outer reveal, a recess and a 45° to 60° splayed inner reveal of obtuse squint quoin form. These jambs are only applied to door and window openings in thick walls either as an architectural feature or to increase the amount of light entering a building. As thick walls are not structurally necessary in the modern steel-framed or reinforced concrete multi-storied type of building, it follows that these jambs are not now so often employed.

The examples shown at A, B, C and D have 2¼-in. recesses, and are therefore suitable for solid framed windows or door frames, whilst the remainder have 4½-in. recesses for the reception of cased framed windows (see pp. 113 to 119, Vol. I). An additional example is shown at W and X, Fig. 19. The suggested bonding of alternate courses in both English and single Flemish bonds is typical only, there being several different arrangements of the bricks. The internal face appearance is only important if the walls are not to be plastered. The bond should be as strong as possible on account of the additional stresses which are transmitted from lintels or arches, and therefore continuous vertical joints should be avoided and the cut bricks should be as large as possible.

The inner reveal may be stepped and not splayed if the internal face of a wall is to be panelled. The plan in outline would then resemble that shown on the right side of the plan at B, Fig. 19. This type is known as a *rebated and stepped jamb*, the stepped recesses varying from 2¼ to 4½-in.

Piers.—Further examples of piers illustrated in Fig. 7, Vol. I, are shown at J, K, L and M, Fig. 12. The alternative plans of *detached squint piers* (J and K)

are typical of those required in the construction of bay windows. The number of joints could be reduced, and greater strength therefore obtained, if purpose-mades were used instead of cut standard bricks.

An example of a *detached octagonal pier* is shown by plans of alternative courses at L, and an *attached octagonal pier* is detailed at M. Other polygonal forms, especially the hexagonal, are sometimes preferred. These may be constructed of standard bricks, cut to shape as required, but a better appearance is, of course, obtained if purpose-made bricks are used. Two further examples of detached piers are shown at R, Fig. 24 (see p. 64).

CAVITY OR HOLLOW WALLS

This type of construction is now very common and, for the reasons stated on pp. 43 and 44, is generally preferred to solid wall construction for many types of buildings, especially houses. Cavity walls are detailed in Figs. 13 and 14.

A cavity wall is usually an external wall, although it is sometimes adopted internally because of its good sound-resisting quality (see p. 49, Vol. III). It consists of two separate walls, known as *leaves* or *skins*, of brickwork, having a cavity between, and connected together by metal ties. This double wall is generally 11-in. thick, consisting of 4½-in. inner and outer leaves and a 2-in. cavity (see A, Q and P, Fig. 13). Such a wall is adequate for a two-storied building of the domestic type. The *inner* leaf is increased to 9-in. or more in thickness when heavier floor, etc., loads have to be supported (see J, Fig. 13 [1]). For stone-faced buildings, the double wall may consist of a cavity between a 4½ to 9-in. stone outer leaf and a 4½-in. or thicker brick inner leaf (see p. 44).

The width of the cavity varies from 2 to 3-in., the latter being the maximum width specified in the Model Byelaws, 1939.

TIES.—These must be sufficiently strong for the purpose, be non-corrodible and so shaped that water from the outer leaf will not pass along them to the inner leaf. The metal ties are usually of wrought iron or mild steel, and these should be thoroughly galvanized or dipped in hot tar and sanded to protect them from rust. Either copper or bronze or similar durable and highly corrosive-resistant metal ties should be selected for important buildings and those near the sea.

Three types of cavity ties which are made of any of these metals are shown at F, G and H, Fig. 13. The wire tie at F is commonly used, and, provided it is of sufficient gauge, is a useful type ; the ends, which are twisted together and turned downwards, cause any water travelling along the tie from the outer leaf to drip into the cavity (see J) clear of the inner leaf ; in addition, large accumulations of mortar droppings, which are a frequent cause of dampness (see p. 42), do not readily lodge on the ties as the wire is comparatively thin. The wire should not be less than 10 Birmingham Wire Gauge (known as " tens " and equivalent to 0·134-in. diameter) ; lighter gauge ties (of 12 B.W.G., termed " twelves " and equivalent to 0·109-in. diameter) are used for cheap work only. A similar pattern, of narrow flat bar section with twisted ends, is shown at H, and is a good type. The flat bar tie shown at G, having forked ends and twisted in the middle, has been used for many years, and affords a stiff and durable connection. Cast-iron ties and hollow glazed stoneware block ties are now very rarely employed.

According to the Model Bye-laws, 1939, these ties must be placed at distances apart not exceeding 3-ft. horizontally and 1-ft. 6-in. vertically, which is equivalent to two per square yard. The ties are staggered and the distribution is as shown at E. Ties should be placed at 1-ft. 6-in. vertical intervals at all angles and door and window jambs to increase stability (see Q and L, Fig. 13 ; E, Fig. 11 ; and D, Fig. 15).

CONSTRUCTION.—A cavity wall is often built with the outer leaf of facing bricks and the inner leaf of commons. No difficulty arises if the facings are thinner than the commons, as the ties are placed at vertical intervals (not exceeding 1-ft. 6-in.) where the bed joints of both leaves approximately coincide. The 4½-in. leaves are commonly constructed in stretching bond. As this has a very unattractive appearance, the monotony is sometimes relieved by constructing the external leaf with a row of snap headers (half bricks) to three or five rows of stretchers (known as *English Garden Wall Bond*, see A, Fig. 18). Alternatively, the outer leaf may be built in Flemish bond or *Flemish Garden Wall Bond*, shown at B, Fig. 18, and A, Fig. 44, snap headers and not whole bricks being used as required. The cut surfaces of these snap headers should be flush with the internal face of the outer leaf.

Two methods of constructing the base of the wall are shown at A and P, Fig. 13. Brick footings are rarely employed. Method A, showing the cavity extending down to the concrete foundation, is common. This has one possible defect, namely, if the brickwork below the ground level is not soundly constructed, especially if the site is water-logged, water may pass through any open joints, collect in the cavity and escape through open joints in the inner leaf, to cause dampness below the floor by spreading over the site concrete. A sounder method, and one which is advocated, is that shown at J and P, where the bottom of the cavity is 3 to 12-in. below the damp proof course. Rain-water gaining access to the cavity through the outer leaf will stream down the inner face of this leaf. This should be prevented from accumulating at the base by providing narrow outlets or *weep-holes* in the course immediately below the damp proof course in the outer leaf, each third or fourth vertical joint between the stretchers being left open and not filled with mortar, otherwise the water may penetrate the brickwork above the damp proof course and cause dampness on the internal face of the wall. See note at J, which shows the detail at the foot of a 15½ or 16-in. cavity wall. The lower portion of the cavity when continued to the concrete bed is sometimes filled with 1 : 2 : 4 concrete, the coarse aggregate being not more than ¾-in. gauge. The top of this concrete should be at least 3-in. below the damp proof course and *not* as shown at F, Fig. 14, otherwise

[1] *See also* J, N *and* R, *Fig.* 7, *Vol. III.*

CAVITY WALLS

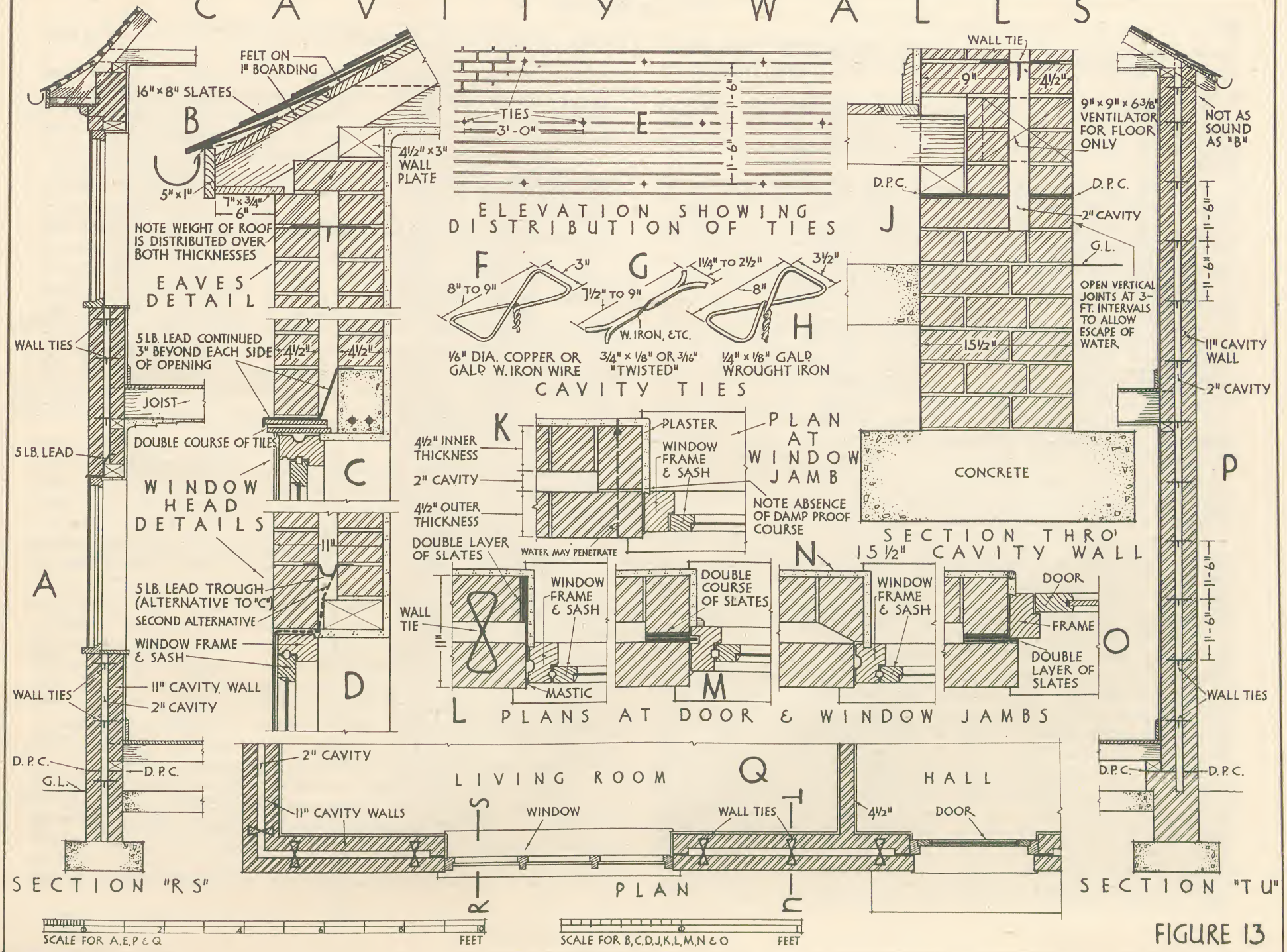


FIGURE 13

mortar droppings (see below) will accumulate through which water may be transmitted in the direction of the thick broken arrow to cause dampness and possibly dry-rot.

The position of the damp proof course is as for solid walls, *i.e.*, at least 6-in. above the ground level. This *must not* extend across the cavity for the reason stated below, and each leaf must therefore be provided with a separate damp proof course.

For cavity wall construction to be effective, it is essential that the inner wall shall be entirely disconnected (except for the cavity ties) from the outer leaf. Where this is not possible, as at door and window openings, special precautions have to be taken, as stated below. If the cavity is bridged by a porous material, water may penetrate and cause dampness on the inner face of the wall. Hence it is important that during construction mortar shall not be allowed to drop and lodge upon the ties (see E, Fig. 14). In order to maintain a clean cavity, a wood batten should be employed of a thickness slightly less than the width of the cavity and with a piece of cord attached to each end. This is supported upon the ties, raised as the work proceeds, and any intercepted mortar and brick chippings removed. Temporary openings should be left at the bottom of the cavity to afford access for the removal of droppings on completion of the wall. Similar gaps should be left at intervals up quoins and jambs through which a lath may be passed to dislodge any deposit on the ties. Another effective method is to flush the whole cavity with water, a hose pipe being used from the top of the wall for the purpose of dislodging any mortar and washing it to the base, from which it is removed through the temporary gaps. *Neglect of this precaution is a frequent cause of dampness in cavity walls.*

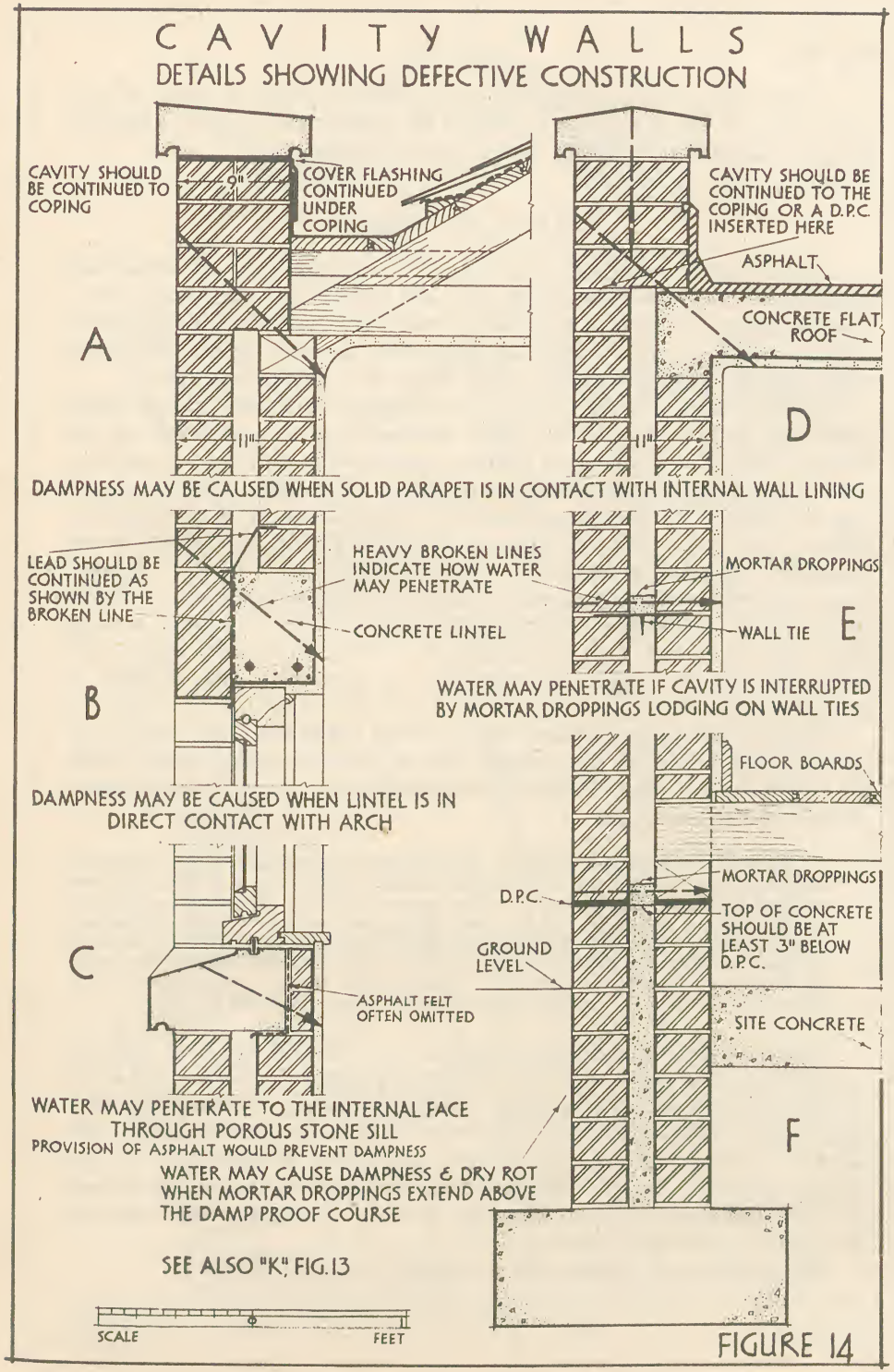
The reason why the cavity should extend below the damp proof course, and for the latter to be in separate widths, will now be appreciated. If the bottom of the cavity is level with the damp proof course, or if the latter is the full width of the wall, water may be conducted to the inner leaf through accumulated mortar droppings, and produce damp and unhealthy conditions.

Alternative details at the eaves are shown at A, B and P. That at A is sound, as the solid portion of wall at the top distributes the weight of the roof over both leaves and the overhanging eaves prevents the transmission of moisture through this solid wall. This is a better detail than that at P, which shows the roof supported chiefly by the inner leaf. Detail B shows sound construction. Special precautions should be taken to prevent dampness at parapet walls. Defective construction is shown at A, Fig. 14, where water may be transmitted through the 9-in. solid parapet wall in the direction of the thick broken arrow to cause dampness and possible defect of the roof timbers. The cavity should be extended to the coping. An example of defective construction associated with a flat roof is shown at D, Fig. 14. The cavity should have been continued to the coping, or, alternatively, either a lead or asphalt felt damp proof course should have been inserted above the cavity where indicated. It is always advisable to continue the asphalt roof covering (or lead flashing) for the full thickness of the wall to prevent the penetration of water through defective coping joints or porous stone or brickwork.

In the absence of adequate precautions dampness will readily occur round door and window openings. An example of unsound construction, commonly adopted, is shown at K, Fig. 13, where water may penetrate in the direction of the thick broken arrow through the solid jamb. A damp-resisting material should be provided as shown at M and O. The former detail shows a double layer of slates, bedded in cement, the outer layer projecting in a groove in the frame ; this groove should be filled with oil mastic as the work proceeds. Effective construction is also shown at O, where lead, asphalt felt or a double layer of slates is applied at the slightly recessed jamb. A small reverse recessed jamb is shown at N, and the bevelled bricks forming the inner reveal only come into contact with the frame, which should be bedded in mastic ; this detail is not recommended for adoption in exposed positions, although it is an improvement upon K. Detail L shows the cavity extending to the opening, and being closed by a double layer of slates in cement. This is quite satisfactory, although not so effective in withstanding heavy loads transmitted from lintels. An alternative method for preventing dampness at jambs consists of placing as the work proceeds a vertical layer of asphalt felt or lead as shown at D, Fig. 32, and A, Fig. 33, Vol. III ; this layer should be 9 in. wide, extending to the groove of the window frame at one edge and into the cavity at the other.

Dampness is very liable to be caused at the heads of openings if proper protection is not afforded. Thus, water passing through defective joints, etc., in the outer leaf will travel down its inner face until it comes into contact with a lintel, when it will spread along the top to the inside face of the inner leaf ; the water will also drip at the soffit. The protection should take the form of a lead, copper or asphalt felt covering, stepped down from the inner leaf, as shown at C, Fig. 13, and continued over the tile course or window (or door) frame, as indicated at A and C, and by broken lines at D (see also D and O, Fig. 28, Vol. III.). This covering should extend for some 3 to 6-in. beyond each side of an opening or end of a lintel in order that the water may drip clear into the cavity. In addition, a few open vertical joints may be left in the brick head to allow any water to escape. The alternative lead trough, shown at D, is *not* recommended, as this does not prevent water from gaining access through defective joints in the head (or porous bricks) and causing dampness. Nor is it sufficient to use a narrow covering with the lower edge bedded in the joint level with the top or above a concrete lintel ; contact between the lintel and the head or arch must be broken by the lead, which is continued as shown by broken lines at B, Fig. 14.

Dampness may also be caused at window sills, especially if these are of porous stone and are in direct contact with the brick backing (see C, Fig. 14). An effective preventive is to break contact by means of a lead or asphalt felt covering as shown by broken lines, or by continuing the cavity (even if reduced in width) to the wood sill or window board. The ends of stone or terra-cotta sills should be notched with the back flush with the inner face of the outer leaf,


CAVITY WALLS
DETAILS SHOWING DEFECTIVE CONSTRUCTION
CAVITY SHOULD BE CONTINUED TO COPING
9"
COVER FLASHING CONTINUED UNDER COPING
A
11"
CAVITY SHOULD BE CONTINUED TO THE COPING OR A D.P.C. INSERTED HERE
ASPHALT
CONCRETE FLAT ROOF
D
11"
DAMPNESS MAY BE CAUSED WHEN SOLID PARAPET IS IN CONTACT WITH INTERNAL WALL LINING
LEAD SHOULD BE CONTINUED AS SHOWN BY THE BROKEN LINE
HEAVY BROKEN LINES INDICATE HOW WATER MAY PENETRATE
CONCRETE LINTEL
B
MORTAR DROPPINGS
WALL TIE
E
WATER MAY PENETRATE IF CAVITY IS INTERRUPTED BY MORTAR DROPPINGS LODGING ON WALL TIES
DAMPNESS MAY BE CAUSED WHEN LINTEL IS IN DIRECT CONTACT WITH ARCH
FLOOR BOARDS
MORTAR DROPPINGS
D.P.C.
TOP OF CONCRETE SHOULD BE AT LEAST 3" BELOW D.P.C.
GROUND LEVEL
C
ASPHALT FELT OFTEN OMITTED
SITE CONCRETE
WATER MAY PENETRATE TO THE INTERNAL FACE THROUGH POROUS STONE SILL
PROVISION OF ASPHALT WOULD PREVENT DAMPNESS
WATER MAY CAUSE DAMPNESS & DRY ROT WHEN MORTAR DROPPINGS EXTEND ABOVE THE DAMP PROOF COURSE
F
SEE ALSO "K," FIG. 13
SCALE
FEET
FIGURE 14

otherwise rain may penetrate through mortar droppings which may lodge on the projecting ends.

If a lean-to or flat roof of a lower building adjoins a cavity wall the usual lead cover flashing should be continued for the full thickness of the outer leaf and be stepped up to the inner leaf. A few weep-holes should also be left in the course of the outer leaf above the flashing. Similarly, when a pitched roof abuts against a higher cavity wall, the stepped cover flashings at the intersection should be continued with upturned edge to 1-in. beyond the inner face of the outer leaf. Such provision is necessary to intercept rain-water streaming down the inner face of the outer leaf and causing dampness to the party wall below.

An additional cavity wall detail showing plans of successive courses at an obtuse squint quoin is given at E, Fig. 11. The external corner brick may be a purpose-made dogleg as shown, or the special squint C, Fig. 5. Alternate plans of an 11-in. circular wall are shown at D, Fig. 15 (see also p. 44). In both details wall ties are shown at the angles in each course to increase stability.

Floor Timbers.—Only sound, well-seasoned timber should be used for floor joists, wall plates, etc., otherwise dampness from the cavity may cause dry rot. It is also a wise precaution to have the wall plates and ends of built-in joists thoroughly creosoted or treated with other preservatives (see pp. 12-14, Vol. III). The risk of dry rot to ground floor (or basement) timbers is considerably reduced if the joists are supported on wall plates bedded on sleeper walls, as shown at E, Fig. 10, Vol. I.

Advantages of Cavity Wall Construction.—The chief merits of cavity walls are: (1) They prevent rain from penetrating to the internal face, (2) they have a high insulating value, and (3) they are economical.

1. *Prevention of Dampness.*—A cavity wall is more reliable than a solid wall of corresponding brick-thickness in excluding rain. Thus, an 11-in. cavity wall in an exposed position will prevent water from penetrating to the inner leaf, provided adequate precautions are taken in its construction and sound materials and workmanship are employed. But an external 9-in. solid wall (which is equivalent in thickness of brickwork to an 11-in. cavity wall) in an exposed position will *not* prevent rain from penetrating to the internal face unless the wall is rough-casted or similarly protected. As has been pointed out on p. 14, a solid wall is vulnerable to dampness by the penetration of rain through cracks in the mortar joints and to other causes, and it is recognized that external solid walls of buildings to be used for human habitation should be at least $13\frac{1}{2}$-in. thick, unless they are rough-casted.

2. *Insulation.*—As air is a good non-conductor of heat, it follows that the air in the cavity is effective in reducing the transmission of heat through the wall. Therefore the " heat losses " through an 11-in. cavity wall are less than through a 9-in. solid wall, and a building of hollow wall construction is warmer in winter and cooler in summer (as the inward flow of the heated external air is impeded) than one built of solid outer walls. This affects fuel consumption, for less fuel is required to heat a building with cavity walls than that of solid wall construction.

An important matter affecting the heat insulating value of a cavity wall is the extent to which the cavity should be ventilated. Formerly, it was generally considered desirable to ventilate the cavity by means of air bricks fixed just above the ground level and also near the top. Whilst this circulation of air ensured a dry cavity and reduced the risk of defects arising in floor timbers, it also destroyed the insulating value of the wall to such an extent that an 11-in. cavity wall so ventilated afforded less heat insulation than a 9-in. solid wall. Therefore the only ventilation of the cavity which is now advocated is that provided by the weep-holes near the base of the cavity and at the head of door and window openings, as described on pp. 40 and 42. Of course the usual ventilation must be provided to ground floors of timber construction.

The sound insulating value of an 11-in. cavity wall is also higher than that of a 9-in. solid wall, and the former is therefore more effective in excluding external noises (see p. 49, Vol. III).

3. *Economy*.—An 11-in. cavity wall costs less to construct than a 13½-in. solid wall (which is the minimum thickness if dampness is to be avoided). Comparative figures show that the approximate cost of an 11-in. wall is at least 20 per cent. less than a 13½-in. solid wall.

Summary of Special Precautions.—1. Wherever possible, contact between the two leaves should be avoided.

2. The cavity should be kept clear of droppings, and any on ties should be removed.
3. The main horizontal damp proof course must be in two separate widths, and the bottom of the cavity must be at least 3-in. below this.
4. Heads of openings must be properly protected by lead or similar damp proof material. Jambs must not be solid unless slate, etc., damp proof courses are provided. Projecting ends of stone or terra-cotta sills should be notched back from the inner leaf. Cover flashings at intersections of lower buildings adjoining cavity walls must extend to at least 1-in. beyond the inner face of the outer leaf.
5. Weep-holes should be formed immediately below the main horizontal damp proof course and above the damp proof courses over openings. No other ventilation to the cavity should be provided.
6. Built-in floor timbers should be sound and well-seasoned and their ends should be treated with a preservative (see pp. 12-14, Vol. III).
7. The cavity should be continued up a parapet wall to the coping.
8. Ties must be rust-proof, capable of preventing rain-transmission and easily cleaned of droppings.

At certain Bath stone mines (see p. 101) small pieces of waste but sound stone are sawn into blocks which are 6¼-in. high (or equal to two courses of brickwork) by 4½-in. wide by 9-in. to 2-ft. long. These are used as facings of 11-in. cavity walls, the stone being in regular courses, a type of walling known locally as *range-work*.

Another type of cavity wall, suitable for public buildings, is shown at A, B and P, Fig. 16, Vol. III. This consists of an external leaf of ashlar, backed at alternate courses with brickwork, and an inner leaf of brickwork.

CIRCULAR WORK

Curved work is occasionally required as for segmental and semicircular bay windows, wells of staircases, apsed ends, and circular (on plan) factory, etc., chimney stacks. The plan of a portion of a room with a semicircular bay window is shown at A, Fig. 15, that on the left being above the sill level and that on the right below it. A sketch of this wall is shown at H, Fig. 27.

It will be seen at E and F, Fig. 15, that uncut standard bricks are quite unsuitable for circular work if normal bonding is to be maintained, as the stretcher faces of the bricks only conform approximately to the curve, and very wide joints on the convex surface are produced. The width of the joints can only be reduced by cutting each brick to a wedge-shape to form radial side joints. Not only is this an expensive procedure but the appearance is not satisfactory (especially if the curve is to a small radius), as the "curve" is made up of a succession of straight stretcher faces. In order to conform more closely to the curve, and when ordinary standard bricks only are available, heading bond (see p. 7, Vol. I) may be adopted. But such a wall, where each course consists of headers, is unattractive in appearance and deficient in strength.

It is now the general practice, even in cheap speculative work, to use only purpose-made bricks for the exposed faces of circular walling. Such bricks are moulded to the required shape either by hand (see p. 4) or by the machine-pressure process (see p. 3).

> Many of the larger manufacturers keep stocks of circular stretchers and headers, machine-pressed in dies shaped to curves of radii varying from 2 to 8-ft., as shown at L and M, Fig. 5. The contractor states the radius of the curve when ordering the bricks. If these do not conform to a stock radius, the plan of the wall is chalked out on the setting-out board and the position of the bricks marked after due allowance has been made for shrinkage in drying and burning. Two zinc templets are cut to the shape of a header and stretcher. Wood moulds (see p. 4) are prepared from these and handed to the moulder who proceeds to shape the bricks by hand.

Alternative plans of a portion of a 13½-in. wall in English bond are shown at C, and of an 11-in. cavity wall at D. Unless both faces of a curved wall are to be exposed, and as purpose-made circular bricks are relatively expensive (especially if hand-made), it is customary to back the curved facings with common bricks which are axed to give radial joints as sown at C. If the internal surface of a cavity wall is to be plastered, the inner leaf is usually built of common bricks (see D), and unless the curvature is too sharp these commons are not cut to give radial joints.

The setting-out of circular work is described on pp. 68 and 70.

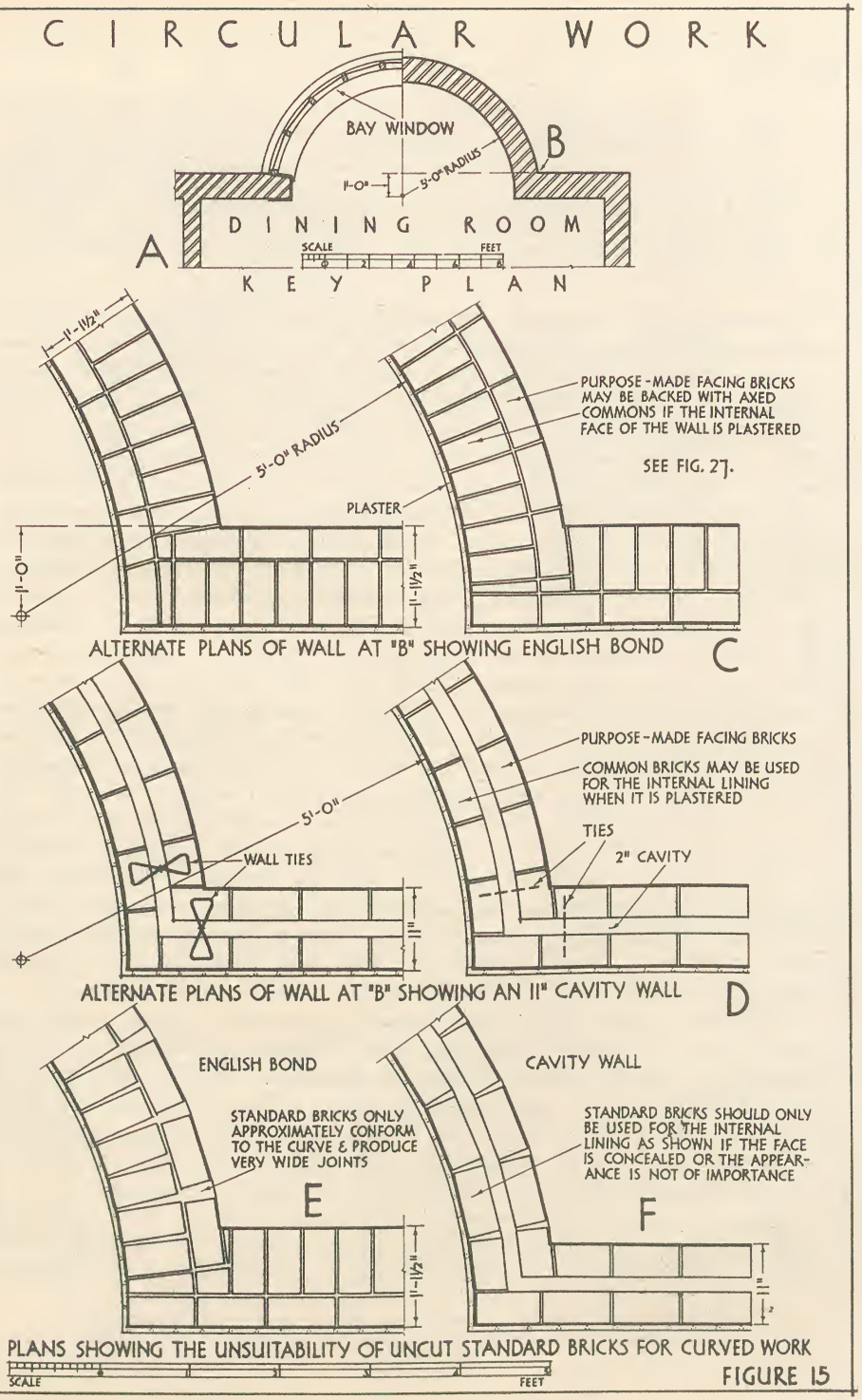


FIGURE 15

REINFORCED BRICKWORK

REINFORCED BRICKWORK (see Fig. 16) is receiving much attention at the present time, and its use is gradually being extended. It is brickwork which has been strengthened by the introduction of steel or wrought iron in the form of either flat or rod bars, woven wire or expanded metal. This reinforcement is placed in the joints or in grooves or perforations in the bricks. Such brickwork is capable of resisting tensile and shear stresses, in addition to compression stress. It is essential that the bricks shall be sound and well burnt, the work well bonded in cement mortar or cement-lime mortar, and the reinforcement effectively protected against corrosion. Rusting of the reinforcement may cause serious damage because of the resultant expansion. Bricks of the engineering type are most suitable when heavy loads have to be supported. The mortar is usually composed of 1 part Portland cement to 3 parts sand; $\frac{1}{10}$ part of slaked lime may be added. Lime mortar should not be used, as this may have an injurious effect on the metal. In accordance with the Model Bye-laws, 1939, a brick wall may be reduced in thickness by $4\frac{1}{2}$-in. provided it is suitably reinforced and such reduced thickness is not less than $8\frac{1}{2}$-in. Hence this type of construction increases the floor area of a building (or reduces the external size of a building) and decreases the dead load on foundations.

Reinforcement of brickwork also improves the longitudinal bond of thick walls. Whilst thick walls are strong transversely, they are weak longitudinally, as, with exception of the outer stretchers, they consist wholly of headers which only give a lap of $2\frac{1}{4}$-in. The details in Fig. 16 show how the provision of reinforcing metal strips increase the longitudinal tie.

Fig. 16 shows examples of reinforced brick (*a*) walls, (*b*) pillars and (*c*) lintels.

(a) *Reinforced Brick Walls.*—The walls at B are shown reinforced at every third course with steel meshed strips called Exmet.[1] This is made from thin rolled steel plates which are cut and stretched (or expanded) by a machine to a diamond meshwork form (see A). It is known as "expanded metal." The junctions between the meshes remain uncut. It is supplied in 270-ft. coils or bundles of 16-ft. long flat strips in three standard widths, *i.e.*, $2\frac{1}{2}$-in. (suitable for $4\frac{1}{2}$-in. walls), 7-in. (suitable for 9-in. walls) and 12-in. (used for $13\frac{1}{2}$-in. walls). Each width is obtainable in 20 (0·035-in.), 22 (0·030-in.) and 24 (0·022-in.) Birmingham Wire Gauge. In addition, $4\frac{1}{2}$-in. width of material in 22 and 24 gauge is also produced. The size of the mesh ($\frac{5}{8}$-in.) is constant. To prevent corrosion the metal in the coil form is coated with oil and then dipped in asphaltum paint. Flat lengths are galvanized.[2]

The Exmet is uncoiled and pressed down into the mortar immediately the latter has been trowelled on the bed. It lies quite flat when uncoiled and the

[1] Manufactured by Messrs The Expanded Metal Co. Ltd.

[2] One method of galvanizing, known as the *hot-dip process*, consists of cleansing the metal and removing any rust by placing it in dilute hydrochloric acid, washing it to remove the acid and then passing it through a bath containing liquid zinc.

thickness of the bed joints is therefore not increased. Hand shears are used to cut the material into lengths as required.

The example at B shows the application of 2½-in. (see A), 7-in. and 12-in. wide Exmet. Combinations of these widths are used for thicker walls, and when so employed, the material considerably improves the longitudinal tie which is especially weak in thick walls. The strips should be lapped 3-in. at the intersections, as shown, and at the joints. Sometimes only 2½-in. wide strips are used for any thickness of wall, one strip to each half-brick thickness of the wall, and is thus similar to that shown at D. The amount of reinforcement used depends upon the nature of the loading, and whilst it may be necessary to reinforce every course, it is usual to provide reinforcement at every third or fourth course. Another arrangement consists of staggering the strips, thus in a 13½-in. wall, one 2½-in. strip is placed on one course at 1-in. from the external face, another strip is provided in the centre of the next course, and in the following course a 2½-in. strip is placed 1-in. from the internal face ; this is repeated for the full height.

Cavity walls (p. 40) may be reinforced by a 2½-in. strip at every third course of each 4½-in. lining. Partition walls, built with bricks laid-on-edge, may also be strengthened by the provision of 2½-in. wide Exmet. The 2½-in. wide strips especially are suitable for curved walls (p. 44), as this width can be readily bent as required. Expanded metal is also used to strengthen walls of chimney stacks and parapets built in exposed positions. Further applications include footings, walling over wide door and window openings, boundary and balcony walls and tall chimneys. Reinforcement of retaining walls, piers and arches is referred to in next column and on p. 48. It can also be usefully employed at toothings (see p. 4, Vol. I) when the bond between new and existing walls at the indents is reinforced if the strips are left projecting beyond the old work and built-in as the new wall is constructed.

Another well-known form of meshed reinforcement, called Bricktor,[1] is shown at C. It is made of steel wire, black japanned as a protection, produced in 2 and 2½-in. widths and sold in coils. The 2-in. width is suitable for brick-on-edge partitions and consists of four straight *tension wires* of 17 B.W.G. (0·058-in. dia.) interlaced with three 19 B.W.G. (0·042-in. dia.) *binding wires*. The 2½-in. strips have five tension wires and four continuous binding wires, each twisted to and between a pair of tension wires as shown. One strip is provided at every half-brick thickness of the wall (see D). It is very easily handled, and is used for similar purposes and in like manner as described for Exmet.

A type of reinforcement much used to strengthen brick walls in the past is shown at E and F. This consists of wrought iron (known as *hoop iron*, hence the name applied to the bond) or mild steel flat bars which vary in width from ⅞ to 1¼-in. and $\frac{1}{16}$ to $\frac{1}{10}$-in. in thickness. Protection against rust is provided by dipping the bars in hot tar ; these are then at once sanded to increase adhesion of the mortar. One strip is provided per half-brick thickness of wall, and it is usual to reinforce every sixth course (see E). This detail shows the treatment at a right-angled quoin where the ends are double-hooked (see J) and beaten flat ; alternatively, the middle and inner strips may be continued and single-hooked (see K) to the two outer strips. At an intersection (see H) the bars are interlaced and single-hooked. Any joints between long lengths are in the form of a welt (similar to D, Fig. 73, Vol. I). Although less effective, thin wire twisted round the bars may be used instead of the more expensive hook-and-welt joints. Hoop iron is now rarely employed, and whilst it is stronger than Exmet and Bricktor, it is more costly. It is also difficult to bed the bricks evenly unless the joints are unusually thick.

Retaining walls (those supporting earth, etc.) are often reinforced. If either of the meshed types are used, 2½-in. strips may be embedded in the vertical joints to assist in resisting lateral pressure in addition to the bed joint reinforcement. Another form of reinforcement consists of vertical bars of circular section, and details of an actual retaining wall[1] of such construction is shown at L, M and N. This 9-in. wall is built of engineering bricks in cement mortar (1 : 3) and reinforced with vertical mild steel bars near each face, in addition to steel meshed strips at every fourth course. The bricks opposite the vertical bars are purpose-made and grooved as shown at P. These grooves are slightly larger than the diameter of the bars to permit the latter to be grouted in with mortar to prevent corrosion. In constructing such a wall the bars are accurately placed in position, the ends being bent and anchored into the concrete foundation (see L). Erection of the bars is facilitated by the use of thin (10 B.W.G. or 0·134-in. dia.) steel wire ties at every fourth course. These ties, which are built in as the work proceeds, are twisted round the bars, and those round opposite bars are tightened by twisting their ends. When the top course has been completed the grooves on face are well pointed so that the vertical rods are completely encased in cement mortar. Vertical damp proofing (see p. 52) completes the wall. If it is an area wall it may be finished with a stone or reinforced concrete coping and the ends of the vertical bars would be bedded in it to strengthen the work.

The walls are designed in accordance with the stresses to be resisted, and the size and spacing of the vertical reinforcement are therefore variable. Sometimes the bars are arranged near to both face lines of the wall, opposite to each other and in pairs at 9-in. centres with steel wire connections placed in the horizontal joints.

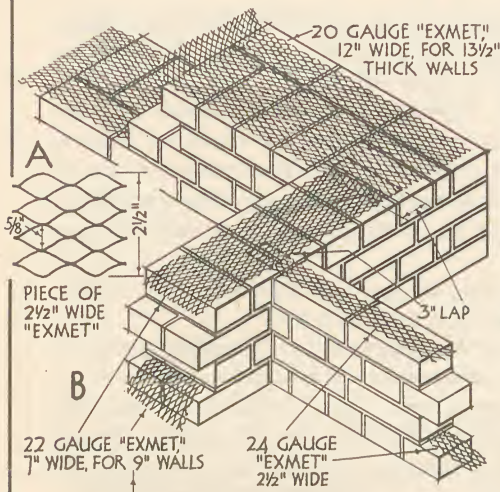
Perforated bricks may be used instead of grooved or slotted bricks, the centre of the perforations being about ¾-in. from the external face. As these must be threaded over the vertical bars, they are not so convenient as the grooved bricks, although they are quite suitable for dwarf walls such as balcony, parapet and garden walls. The position of the vertical bars is concealed when perforated bricks are used in wall construction, and such are therefore preferred to grooved bricks when the appearance of the brickwork is of importance.

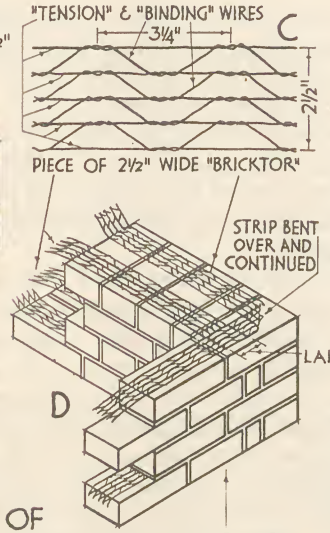
Many air-raid shelters have been constructed of reinforced brick walls. In such work the vertical bars are placed in position and the brickwork built round them. Special bricks are not employed, ordinary stocks being cut as required.

[1] A product of Messrs Johnson's Reinforced Concrete Engineering Co. Ltd.

[1] Constructed by the patentees, Messrs B. Morton & Sons, Manchester.

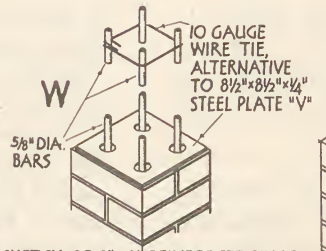
REINFORCED BRICKWORK



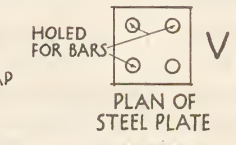


APPLICATIONS OF "EXMET" & "BRICKTOR"

SCALE OF INCHES FOR A,C,J & K

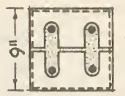


SKETCH OF 9"×9" REINFORCED PILLAR

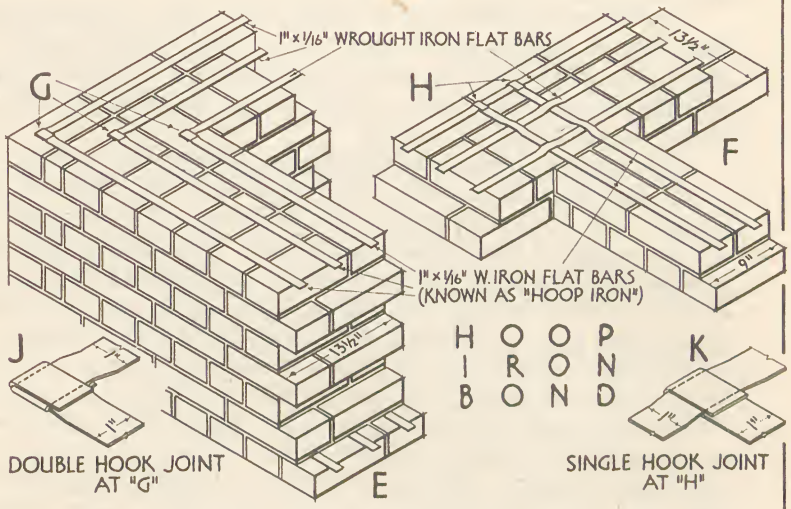


PLAN OF STEEL PLATE

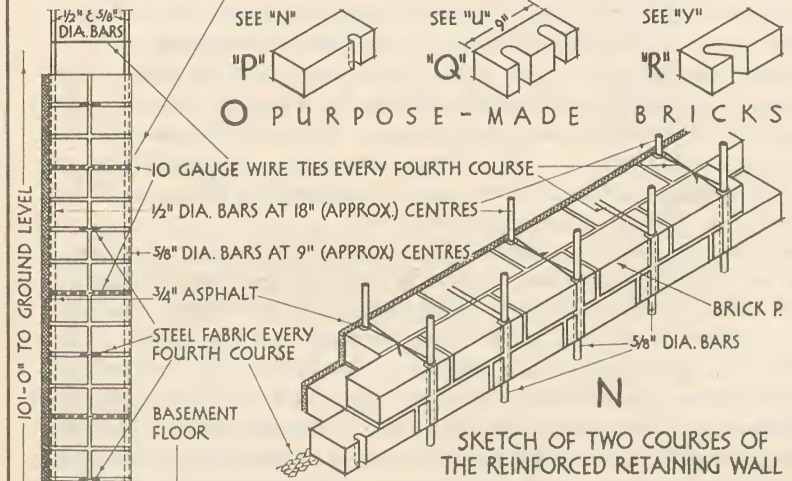
PLAN

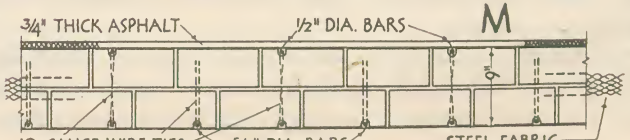


PLAN



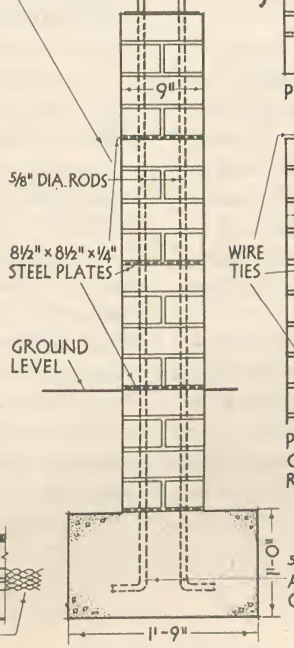
REINFORCED RETAINING WALL & PILLARS

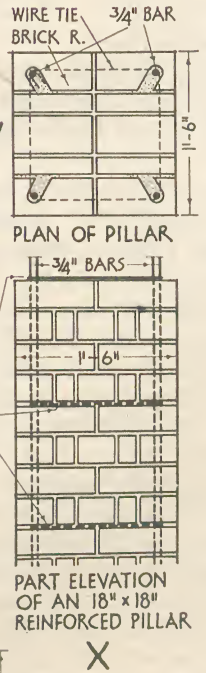




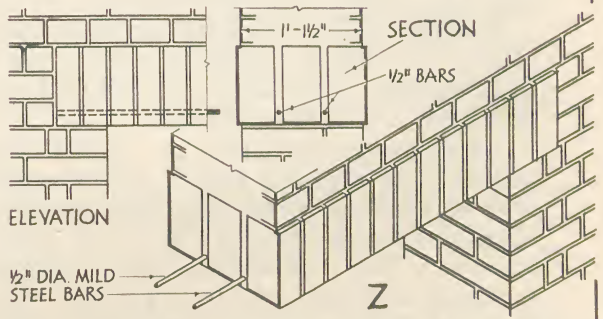
PLAN OF RETAINING WALL

SCALE FOR B,D,E,F,L,M,N,O,S,T,U,V,W,X,Y,Z & Z' FEET

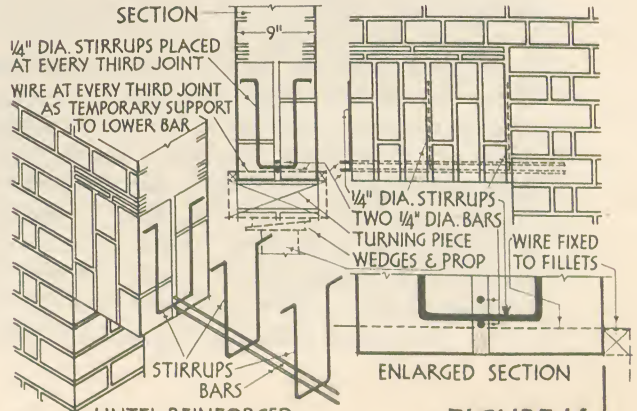




LINTELS



LINTEL REINFORCED WITH BARS BETWEEN VERTICAL JOINTS



LINTEL REINFORCED WITH BARS & STIRRUPS

FIGURE 16

Small bars of circular section (usually ¼-in. dia.) are sometimes used at the bed joints of walls in lieu of hoop iron or meshed reinforcement. Thin steel plates, ¼-in. thick and ½-in. less in width than the thickness of the walls, may be embedded at every fourth course to provide heavy reinforcement. Such should be well tarred and sanded.

A patent type of reinforced partition is described on p. 45, Vol. III.

(b) *Reinforced Brick Pillars.*—Detached piers are reinforced by providing a 2½-in. wide strip of Bricktor or Exmet set back 1-in. from the external face at every second or third course or as required. Alternatively, ¼-in. diameter rods may be embedded at the bed joints, each rod being bent to the shape of the pier, about 1-in. from the face, with each end overlapping about 6-in. at one corner. An excellent type of reinforced pillar [1] is shown at S, T, U, V and W. This 9-in. square pillar is reinforced with four steel rods, well anchored into the concrete bed, and steel plates (see V) or wire ties (see W) embedded at every fourth course. The purpose-made bricks are shown at Q, T and U. Note that the bars are well protected against corrosion by the mortar. Details of an 18-in. square pillar are shown at X and Y, including a sketch of the special bricks at R; holed steel plates may be adopted in lieu of the wire ties when a heavier reinforcement is required. Perforated bricks may be used, but as these have to be threaded over the rods they are not so convenient as the grooved bricks.

Attached piers are reinforced by 2½-in. wide strips of Exmet or Bricktor, placed 1-in. from the face and lapped over the continuous outer strips on the wall bed joints. Alternatively, two vertical bars with special bricks, similar to that shown at R, may be preferred.

(c) *Reinforced Brick Lintels or "Soldier Arches."*—These lintels must be provided with additional support when the span exceeds 3-ft. Omission of adequate reinforcement has been responsible for many failures. Two methods of reinforcement are shown at Z and Z′, Fig. 16 (see also Fig. 12, Vol. I). That at Z shows the lintel reinforced with two ½-in. diameter mild steel bars embedded in the longitudinal joints and extending to 6-in. beyond the jambs. The alternative form at Z′ shows two ¼-in. diameter bars or tension reinforcement embedded in the continuous longitudinal joint, together with ¼-in. diameter bent steel bars, called *stirrups*, bedded in every third vertical joint. The object of the stirrups is to resist shear stresses.

In constructing the lintel at Z′, two small wood fillets are nailed to the top of the turning piece (used as a temporary support) at a clear distance apart equal to the thickness of the lintel. Pieces of thin wire are placed transversely across and nailed to the fillets at a spacing equivalent to the centre of every third vertical joint. The bottom bar is placed centrally on the wires and built in at the ends. The bricks of the lintel are laid (working from each end towards the centre), and at the same time the stirrups, supported by the bottom bar, are bedded in position at every third joint, care being taken that the continuous longitudinal joint is filled with mortar for the lower 2-in. only. The top rod is inserted and pressed down to the stirrups or to a level slightly above them. The continuous vertical joint is then filled with grout from the top. Prior to the removal of the turning piece, the pieces of thin wire are cut flush with the two faces and the ends turned into the joints. Pointing completes the lintel. A 1-in. by ½-in. wood fillet may be used as a temporary support for the lower tension bar in lieu of the pieces of wire. This must be oiled before being built in to permit of its removal after the turning piece has been removed. The continuous joint is filled in with cement mortar and the soffit pointed after this fillet has been removed.

The size and number of bars vary with the span and loading. That shown at Z′ is typical for a lintel having a maximum span of 8-ft.

Flat and segmental arches may be strengthened by embedding meshed reinforcement in the bed joints of the walling which they support.

Reinforced brickwork has been adopted in the construction of fire-resisting floors. These slabs are reinforced with bars between the joints of the bricks placed on edge, both transversely and longitudinally, and these slabs are supported by steel beams at a maximum distance apart of 7-ft. Reinforced slab construction is necessary for large brick canopies over doorways, etc.

Raking Bonds.—A characteristic defect in a thick wall built in English bond is a deficiency in the longitudinal bond due to the absence of stretchers in the heart of the wall. As stated on p. 46, this tie may be improved by the provision of metal reinforcement. An older method, and one which is now only occasionally adopted, is the introduction of courses of bricks set at a rake (or inclination) at intervals up the wall. These are known as raking bond courses and are of two forms, *i.e.*, (*a*) diagonal bond, and (*b*) herring-bone bond.

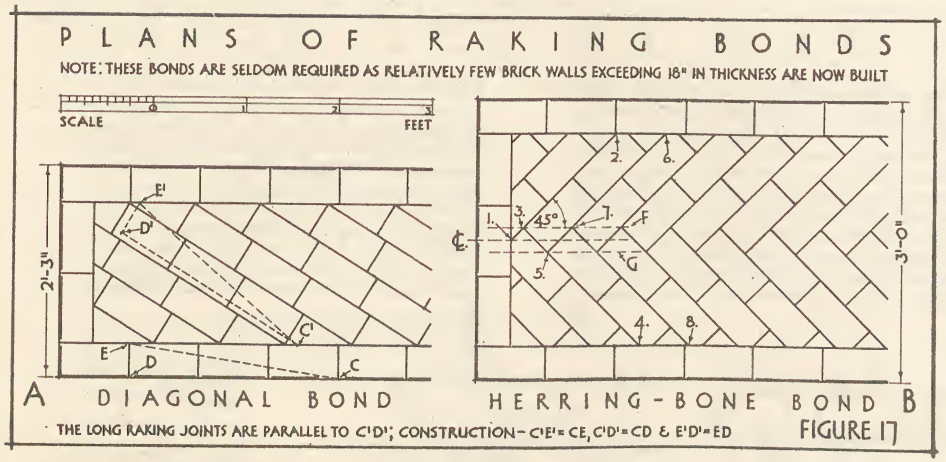
(a) *Diagonal Bond* (see plan A, Fig. 17).—This is best suited for walls which are from 3 to 4-bricks thick, and is applied between the *stretching* [1] faces at every fifth or seventh course. Alternate raking courses should be inclined in the opposite direction to that shown. The method of setting-out is indicated on the figure. The triangular spaces formed near the stretching faces should be filled in with cut pieces of brick and not mortar only.

(b) *Herring-bone Bond.*—This form (so-called because of its slight resemblance to the spine of a herring) is shown at plan B, Fig. 17, and may be applied to walls which are at least 4-bricks thick at five to seven course vertical intervals. The bricks are laid at an angle of 45° in both directions from the centre. Like diagonal bond, alternate herring-bone courses are reversed. The setting-out is shown in the figure. Note (1) the construction lines F and G are drawn parallel to and equidistant from the centre line, with the 45° distance between (as 3-5) equal to 4½-in. or the width of a brick, and (2) the long raking joint 1-2 is drawn from the centre and inclined at 45°, followed in sequence by the long raking joints 3-4, 5-6, 7-8, etc.

An alternative to raking bonds for increasing the longitudinal tie in thick walls is known as *longitudinal bond*. A course built in this bond consists entirely

[1] By courtesy of the patentees, Messrs B. Morton & Sons, Manchester.

[1] Raking bond courses in brick footings should be between the normal *heading* faces.


PLANS OF RAKING BONDS
NOTE: THESE BONDS ARE SELDOM REQUIRED AS RELATIVELY FEW BRICK WALLS EXCEEDING 18" IN THICKNESS ARE NOW BUILT
SCALE
FEET
21-3"
3'-0"
A DIAGONAL BOND
HERRING-BONE BOND B
THE LONG RAKING JOINTS ARE PARALLEL TO C'D'; CONSTRUCTION - C'E' = CE, C'D' = CD & E'D' = ED
FIGURE 17

of stretchers, with exception of a row of queen closers adjacent to each outer row of stretchers. The inner rows of stretchers are arranged to break joint to give a 4½-in. lap. This bond may be applied at every fifth course.

The above three bonds are seldom required for constructional purposes, as modern steel-framed and reinforced concrete construction has, to a large extent, eliminated thick walls. Both forms of raking bonds are, however, often used with good effect in decorated brickwork. Examples of such brickwork are shown in Fig. 24, the panel at M.1 indicating diagonal bond and that at M.2 showing the bricks arranged to a herring-bone pattern (see p. 62).

SPECIAL BONDS

Bonds which have not already been described include Garden, Cross, Dutch, Brick-on-edge and Facing Bonds.

GARDEN WALL BOND.—As its name implies, this bond is suitable for garden, division and similar walls which usually do not exceed 1-brick in thickness. Owing to the slight variation in the lengths of bricks it is difficult to construct a 9-in. wall in English bond if a fair or uniform face is required on both sides (see p. 7, Vol. I). As fewer headers are employed in garden wall bond than in either English or Flemish bonds, it is usually possible to select from the bricks available sufficient of the longer bricks of uniform length as headers for a garden bonded wall, the remaining bricks being used as stretchers and built flush with both faces of the headers. Fair faces on both sides of a garden bonded wall are thus ensured. Whilst garden wall bond is not as strong as English bond (the transverse tie being inferior), it is sufficient for most dwarf walls and for those not required to withstand large stresses. As mentioned on p. 40, garden wall bond is sometimes used instead of stretching bond for the construction of the outer leaves of cavity walls. It has a good appearance, and on this account is greatly to be preferred to stretching bond.

There are two forms of garden wall bond, *i.e.*, (*a*) English garden wall bond and (*b*) Flemish garden wall bond.

(a) *English Garden Wall Bond* (see A, Fig. 18).—This consists of one course of headers to three or five courses of stretchers. As in English bond, a queen closer is introduced next to the quoin header in the heading course. A header is placed at the quoin of each middle (or alternate) course of stretchers to give the necessary lap and face appearance of stretching bond (see also H, Fig. 3, Vol. I). The longitudinal vertical joint between each three (or five) successive stretching courses is continuous, and this causes the deficiency in transverse strength stated in the preceding column. This bond, because of its economy, is very frequently adopted in the construction of 9-in. thick rough-casted external walls, especially for houses not exceeding two stories in height.

(b) *Flemish Garden Wall Bond* (see B, Fig. 18).—This is also known as *Sussex* and *Scotch* bond. It consists of three or five stretchers to one header in *each* course. A three-quarter bat is placed next to the quoin header in every alternate course, and a header is laid over the middle of each central stretcher.

In a modified arrangement at the quoin of a Sussex bonded wall, a queen closer is placed next to the quoin header of each alternate course, and this is followed by a series of three stretchers and a header. Each alternating course comprises a quoin stretcher with a stretcher adjoining, followed by a series consisting of a header and three stretchers. Excepting at the quoin the appearance is similar to the above, as each header is centrally over the middle stretcher.

MONK BOND is a variation of Flemish garden wall bond, *each* course consisting of a series comprising a header and two stretchers, the header falling centrally over the joint between a pair of stretchers.

ENGLISH CROSS BOND (see C, Fig. 18).—This is similar to English bond, in that it consists of alternate courses of headers and stretchers, with queen closers next to the quoin headers. Each *alternate stretching* course has, however, a header placed next to the quoin stretcher. This causes the stretchers to break joint in alternate courses.

DUTCH BOND (see D, Fig. 18).—This is another modification of English bond. The bond consists of alternate courses of headers and stretchers, but *each stretching* course begins at the quoin with a three-quarter bat, and every *alternate stretching* course has a header placed next to the quoin three-quarter bat. This also has the effect of the stretchers breaking joint in alternate courses. The presence of the quoin three-quarter bats makes it unnecessary for queen closers to be placed next to the quoin headers as in English bond.

BRICK-ON-EDGE BONDS.—These differ from normal bond in that at least alternate courses are 4½-in. high, the bricks being laid on edge and not on bed. They are economical as, compared with English bond, considerably fewer bricks and less mortar are required. Their strength is deficient, and the appearance is unsatisfactory on account of the large scale of the brick units and the light colour which is characteristic of the beds of most bricks. Only wire-cut bricks should be used. These bonds are sometimes employed for garden and similar walling,

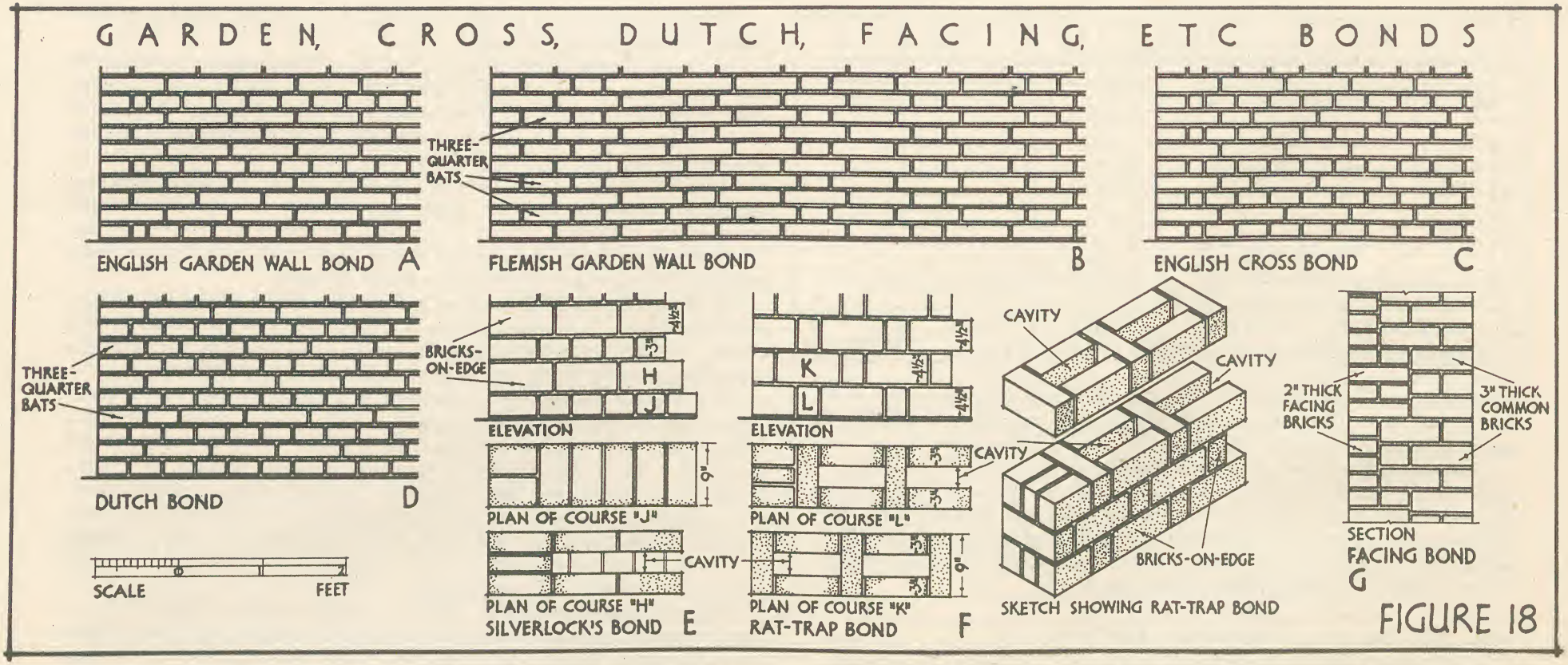


FIGURE 18

and occasionally for walls of cheap one-storied cottages. They can be employed effectively if their external faces are covered with vertical tiling (see p. 111, Vol. III). The best known brick-on-edge bonds are (*a*) rat-trap bond and (*b*) Silverlock's bond.

(a) *Rat-trap Bond* (see F, Fig. 18).—All bricks are laid on edge, and, as shown, are arranged to give a face appearance of Flemish bond. Each alternate course L commences with a three-quarter bat, followed by a header, and each alternate course K commences with a header, succeeded by a stretcher. As indicated on the plans, there is a 3-in. cavity between each pair of stretchers, except at the jambs, which are solid (see also sketch). It is estimated that, compared with a 9-in. solid wall, a rat-trap bonded wall shows a saving of approximately 25 per cent. External walls of cottages built in this bond must be protected on their outer faces by rough-cast or vertical tiling, otherwise water may penetrate through the solid headers and mortar droppings.

Occasionally 9-in. rat-trap bonded walls are built solid, the cavity being filled by stretchers placed on edge.

(b) *Silverlock's Bond* (see E, Fig. 18).—This resembles English bond in that it consists of alternate courses of headers and stretchers, but, whereas the headers are laid on bed, the stretchers are placed on edge with a continuous cavity between. The jambs are solid, and a three-quarter bat at the beginning of each heading course gives the necessary bond. Whilst this is stronger than rat-trap bond, it is not so economical.

On the score of economy in materials and space, brick-on-edge stretching bond is frequently employed in the construction of 3-in. thick partition walls in lieu of $4\frac{1}{2}$-in. thick brick walls.

Facing Bond.—This is usually employed for solid walls exceeding 9-in. in thickness which are faced with thin bricks and backed by thicker and cheaper standard commons. The faced work is bonded to the backing in a series of blocks of a height which depends upon the difference in thickness between the two types of bricks. Thus, in the section through the 18-in. wall at G, Fig. 18, the height of four courses of 2-in. thick facings with their bed joints is shown to coincide with three courses of commons together with their joints, and the

blocks of facings are alternately ½ and 1-brick thick. The facings may be built in either English, Flemish or any of the bonds A, B, C or D, Fig. 18 (with snap headers at the ½-brick thick blocks), and the backing is built in English bond. Somewhat similar construction may be applied to 1½-brick walls, with the backing to the alternating 9-in. thick facing blocks built in stretching bond.

A modified form of facing bond may be applied to 9-in. thick walls. Thus, the facings and commons would be built in ½-brick thick leaves in stretching bond with facing heading courses at suitable intervals. If the facing and backing bed joints coincide, as shown at G, such facing headers would appear at every fifth facing course.

Facing bond is not, of course, as strong as English bond, but the alternative would be to use thin bricks for the backing of the same thickness as the facings. And this would add considerably to the cost, especially if the facings were 2-in. or less.

ARCHES

A description of several forms of arches is given on pp. 22-26, Vol. I.

SEMICIRCULAR ARCH WITH ORDERS.—An opening in a thick wall is often finished with either splayed or stepped jambs (see p. 39) and an arch comprising several rings of diminishing width or thickness. The arch is thus recessed or stepped by a series of rings known as *orders* (or " rows "). It is applied to both door and window openings and has a satisfactory appearance.

An example of this type of arch is shown at A, B and C, Fig. 19, which illustrates a main entrance to a house. Special attention is drawn to the section at C, which shows the bonding of the arch as each ring extends to the inner face. This is known as a *bonded* arch. It is much stronger than the alternative unbonded arch, often applied, when 4½-in. by 4½-in. by 3-in. voussoirs are used for each ring which is therefore only 4½-in. wide on soffit. The impost is shown consisting of a double row of tiles which project ¾-in. An alternative is a thin stone course or a course of purpose-made bricks.

It is assumed that the door shown opens into an outer lobby, otherwise the thickness of the wall should be increased, with the inner ring at least 9-in. wide on soffit.

The two steps, of combined height equal to the brick-on-end plinth, are formed with bricks-on-edge in cement. These bricks must be hard and durable, otherwise the arrises would be readily damaged. The bottom step is segmental with a 4-ft. radius, and consists of purpose-made bricks with a tile-on-edge infilling ; the vertical joints are radial.

Another example of a semicircular arch with orders is shown at P.14, Fig. 24. This arch is three-ringed and the stepped recesses are continued down the jambs to the steps of the doorway. This is an alternative treatment to the splayed jambs shown at A, Fig. 19 (see also p. 64).

A semicircular arch with a toothed or *indented* extrados is shown at P.13, Fig. 24 (see also p. 64).

STILTED SEMICIRCULAR ARCH WITH SEGMENTAL RERE ARCH (see U, V, W, X and Z, Fig. 19.)—A stilted (or elevated) arch is one which has its springing line above the impost. Thus, the amount of stilting of the semicircular arch at U is equal to two courses. In the absence of an impost the arch is continued below the springing line with several parallel voussoirs, any difference in texture and colour between the voussoirs and general walling producing the stilted effect. This arch is enriched by a slightly projecting crown course known as a *label* (see U and the section at Z). When the label consists of moulded bricks (or stone) it is called a *hood mould*. The voussoirs and label are of purpose-made bricks, and the arch is bonded on face.

When the jambs of an opening are rebated, the external arch need not necessarily be of the same shape as the internal arch. Thus the external arch at U is semicircular of 2-ft. 3-in. radius, and the inner arch is segmental of 6-ft. radius. As the internal jambs are splayed, as shown at W and X, the intersection between the soffit of the segmental arch and a splayed jamb will take the form of a curve as indicated at Z. This segmental arch is known as a *rere* (meaning " back " or " rear ") *arch*.

The development of the curved intersection is shown at X, V and Z. The plan at X and sectional elevation Z of the splayed jamb are each divided into four or any convenient number of equal parts. Vertical lines are projected from the quarter-points 1, 2 and 3 on the plan to the intrados of the segmental arch. Horizontal lines are drawn from the points 5, 1, 2, 3 and 4 on the intrados to intersect the corresponding vertical lines at Z. A line 5, 1, 2 3 and 4 drawn through these points of intersection gives the required curve, as shown at Z. Horizontal lines projected from the voussoir joints at the intrados of the segmental arch at V to Z give the level soffit joints in section YY.

CIRCULAR OR BULL'S-EYE ARCH (see H, Fig. 19).—This form of arch is chiefly adopted as an external decorative feature to receive either a fixed light or frame with a pivoted sash. Circular openings in internal walls are occasionally required through which metal smoke flues, ventilating tubes, etc., are passed. Purpose-made, rubber or axed bricks are used externally, and an internal arch is usually a rough ring.

Construction.—The lower half or *invert* of this arch is first built. The adjacent brickwork which will form the base for this lower half is built from course Z and racked back up to course Y at the centre. A wood batten is laid across the opening and weighed at the ends on course Y, and the trammel rod or *radius rod* (see p. 85, Vol. I) is screwed or nailed to it at the centre ; allowance for the thickness of the bed joint at the extrados must be made in determining the length of the rod. Course Z is completed ; stretchers 1, 2 and 3 are laid temporarily in position and marked to the required curve as the radius rod is traversed ; these bricks are cut with a hammer and bolster (see 35, Fig. 19, Vol. I) and trimmed accurately to shape with a scutch ; they are then laid permanently. Each course up to the middle line is completed in this manner, after which the purpose-made voussoirs forming the lower half of the arch are bedded in position, the radius rod being used to check the radial joints and curve. Finally, the upper half of the arch is constructed by the usual method, a wood centre on struts being used as a temporary support (see p. 60, Vol. III).

SEMI-ELLIPTICAL ARCH (see J, Fig. 19).—This shows half of an axed arch, bonded on face with a portion of a tiled key, and a half arch in three rough rings. Both purpose-mades and rubbers may be used for the former.

This form of arch has several demerits. It is not structurally sound, as defects such as shearing at the haunch joints may occur, especially if the rise is relatively small. Labour costs are high, as special care must be taken in its setting-out and erection if abnormally shaped curves at the intrados and extrados are to be avoided. It is sometimes preferred to the segmental arch where a comparatively large span is required and the height is restricted. The rise of the arch should be at least one-third the span.

As the student will be aware, an ellipse is produced when a cone is cut by a plane which does not intersect the base and is not parallel to it. A true elliptical curve cannot be constructed with compasses, as no part of it is circular. However, for reasons of economy and the need to reduce the number of voussoir templets to a minimum, it is usual to adopt a geometrical method for setting-out the intrados and extrados of a semi-elliptical arch. There are several methods, that set out from five centres shown at J being one of the best, as by it compound curves can be produced which closely conform to that of the true ellipse.

Setting-out.—Draw the major and minor axes ; make *cd* = half span *ab* ; construct circle with *d* as centre and *db* as radius, and mark off *be* and *bf* = radius *db* ; draw lines *dem*, *dfr*, *ken* and *kfo* ; *g*, *e*, *k*, *f* and *h* are the five required centres for both the intrados and extrados, and *dm*, *kn*, *ko* and *dr* are common normals. Construct tangential curves *as*, *st*, *tu*, *uv* and *vw* with *g*, *e*, *k*, *f* and *h* as centres respectively ; construct the extrados in a similar manner ; mark off the thickness of the voussoirs on the extrados (if the bricks are axed, purpose-made or rubbed) and draw the bed joints of the voussoirs. It is important to note that these joints are radial, as shown by the broken constructional lines ; thus the voussoirs within the portion of the arch *mnts* radiate from centre *e*, and those within portion *nout* radiate from centre *k*. It will be seen that the bricklayer will only require three differently shaped templets to which axed or rubber voussoirs are shaped, *i.e.*, one for the central voussoirs, one for those within the intermediate portions *mnts* and *orvu*, and one templet for the voussoirs within the two end portions. Also for purpose-mades, three similarly shaped but larger (to allow for shrinkage) moulds will serve the moulder to shape the bricks.

Elliptical Arch (see K, Fig. 19).—This may be adopted as an alternative to the circular arch H. The method of setting out briefly indicated in the figure has been selected as an alternative to that described for the semi-elliptical arch J. It will be seen that only four centres *e*, *m*, *n* and *f* are required.

Setting-out.—After the major and minor axes have been drawn and their lengths decided upon, with centre *a* and radius *ab* describe arc *bc* ; join *bh*, with centre *h* and radius *hc* describe arc *cd* ; bisect *bd*, and the two centres *e* and *f* are at the intersection between this bisector and the two axes ; the two remaining centres *m* and *n* are easily obtained by making *am* = *af* and *an* = *ae*. The voussoir joints of each of the four sections of the arch radiate towards its centre. Only two templets are required for the whole of the voussoirs.

Pointed Arches.—These are also known as Gothic arches, as the pointed arch is characteristic of this style of architecture. The intrados and extrados of each of the several forms of this type of arch are segmental curves which intersect at the pointed apex at which each half abuts to form a vertical joint on the centre line. It is therefore not usual to have a key.

There are five forms of pointed arch, *i.e.*, equilateral, drop, lancet, Tudor and Venetian.

The first three are illustrated at T, Fig. 19. The *equilateral arch* is shown at R, bonded on face ; the radius of each curve of the intrados equals the span, the centres are at the *ends* of the springing line and the extrados is parallel to the intrados. A *drop arch*, as at Q, has its centres on the springing line and *within* it ; in the example the span is 4-ft. 6-in. and the radius is 3-ft. 9-in. A *lancet arch* has its centres on the springing line and *outside* the span ; that shown by broken lines at S has a span of 2-ft. 3-in. and the radius is 2-ft. 7½-in. In each form the bed joints of the voussoirs radiate to their respective centres. The equilateral and drop arches are shown in section at O.

Tudor Arch (see N, Fig. 19).—This arch, commonly employed during the Tudor period, has four centres, all within the span ; two of them are on the springing line and the other two are below it. The Tudor arch, like the semi-elliptical, is a weak form.

Setting-out.—There are several methods. In that shown, *ac* is set up and made equal to ⅝ (or ⅔) rise *em* ; join *mc* and draw *mn* at right angles to it of indefinite length ; mark off *mn* and *ar* = *ac* ; join *nr*, bisect it and continue the bisector until it intersects *mn* continued at *s* ; *s* and *r* are the required centres for the right half of the arch, and *sr* produced to *u* is a common normal. The remaining two centres *v* and *w* may be found by measuring from the centre line. The voussoir bed joints radiate from the respective centres. Two templets are required for the voussoirs.

Venetian Arch (see L, Fig. 19).—This pointed arch is deeper at the crown than at the springing line. The centres are on the latter. The voussoirs are radial from the centres of the *intrados* curves.

Florentine Arch (see M, Fig. 19).—This, like the Venetian arch, is deeper at the crown than at the springing. The intrados curve is semicircular, and the extrados has a pointed apex as it consists of two segmental curves, as shown. Here also the voussoirs are normal to the *intrados* curve. Sometimes the extrados is semi-elliptical.

A *semi-hexagonal arch* and a *tiled segmental arch* are illustrated in Fig. 24 (see p. 64). Note also the flat arch at H, Fig. 24, Vol. III.

The centering for the above arches is described on pp. 60 and 62, Vol. III.

DAMP PROOFING OF BASEMENTS

The materials used for horizontal damp proof courses and their application are described on pp. 17 and 18, Vol. I. Vertical damp proof courses will now be considered.

The materials chiefly used for vertical damp proof courses are (1) bituminous substances and (2) waterproofed cement and concrete.

1. Bitumen is a name applied to natural pitchy (see p. 54) substances consisting principally of hydrocarbons which vary in colour and hardness. It includes (*a*) natural asphalt, (*b*) artificial asphalt and (*c*) fibrous asphalt felt.

ARCHES

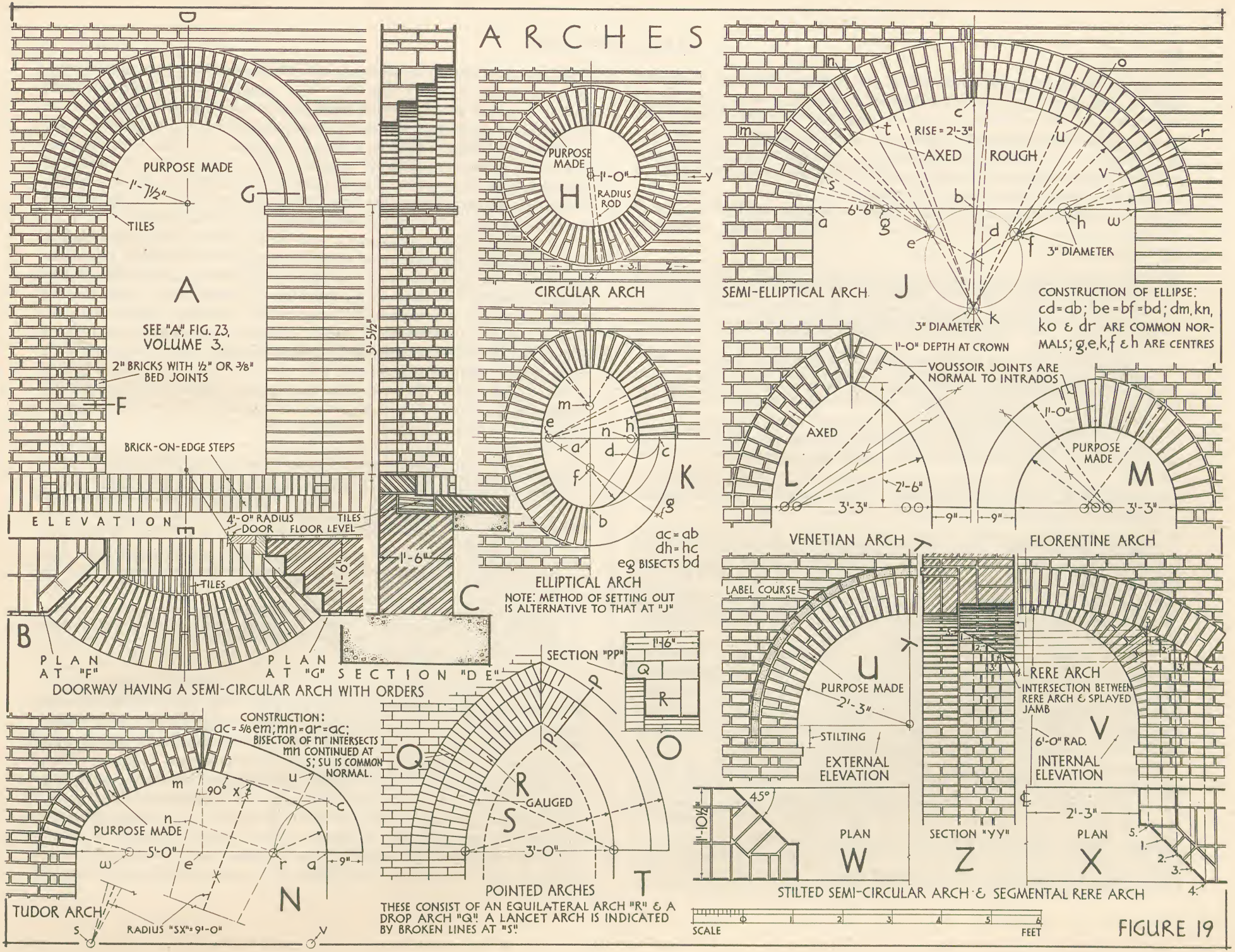


FIGURE 19

(a) *Natural* or *Native Asphalt* occurs in many parts of the world in either a pure (or moderately pure) condition or associated with a large proportion of mineral matter such as limestone, shale, etc., and known as *rock asphalt*. It is found in liquid form in springs, liquid or semi-liquid condition in lakes, and in impregnated rock formation. As there are no deposits in this country, asphalt has to be imported, the chief supplies being obtained from the British West Indies, France, Switzerland and Germany.

Natural asphalt is one of the most efficient materials employed for damp resisting purposes; it is black in colour, very durable, tough, elastic and noiseless.

One of the largest deposits of asphalt exists on the Island of Trinidad, British West Indies. It is a lake, known as Trinidad Asphalt Lake, approximately circular, of 2,000-yd. in diameter and nearly 300-ft. deep. Whilst large quantities of asphalt have already been obtained from it, it is estimated that there still remain some 10 to 15 million tons. The consistency of the asphalt is such that it will permit men to work on the surface.

The chief supply from France comes from a large deposit in the Seyssel region and is commercially known by that name. Another source is that from a deposit mined in the south (St Jean de Maruéjols, Department of Gard). These are rock asphalt deposits, the limestone having a maximum asphalt impregnation of 12 per cent. It is both quarried and mined.

The largest deposits occuring in Switzerland are in the Val de Travers region, west of Lake Neuchatel, and well known as Val de Travers and Neuchatel asphalts. This is asphalt-impregnated limestone, the asphalt content varying from 8 to 12 per cent.

The principal deposit in Germany is situated at the village of Limmer (in the province of Hanover) and is marketed as "Limmer Asphalt." This is limestone which is impregnated with 8 to 20 per cent. of asphalt.

Winning and Refining.—The methods employed to obtain asphalt depend upon the nature of the deposits. Thus, Trinidad Lake asphalt is hand-picked by men working on the surface, loaded into trucks which are hauled by cable over rails either to the refiners or to the shore (about ¾-mile distant) and loaded for direct shipment. Deposits of rock asphalt near the surface are open-quarried, blasting being resorted to. Deep deposits are mined.

Water is present in most natural asphalts. That from Lake Trinidad, for instance, has nearly 30 per cent. of moisture content. This must be removed. Dehydration is effected by heating the asphalt in open metal tanks, after which it is passed through a fine screen (to remove pieces of wood, etc.), and poured into barrels. Rock asphalts are crushed, ground and screened before being either heated in tanks or dried by exposure to the atmosphere.

Preparation of Natural Asphalt Mastic.—This is recognized as one of the most reliable materials for the damp proofing of walls, floors and flat roofs. As, for this purpose, most rock asphalts are deficient in bitumen, it is necessary to enrich them by the addition of Trinidad Lake asphalt. The rock asphalt or aggregate used in the preparation of the mastic should contain at least 90 per cent. of calcium carbonate and not less than 8 per cent. of bitumen. This rock is reduced by grinding to a powder so that the whole will pass a No. 8 sieve (mesh of 0·081-sq. in. aperture) and at least 15 per cent. will pass a No. 200 sieve (mesh of 0·003-sq. in. aperture). The required amount of Trinidad Lake asphalt is added and thoroughly incorporated by mechanical agitators with the powdered aggregate in a tank at a temperature of from 350° to 400° F. The total bitumen content should be at least 16 per cent. In order to stabilize the mastic and render it suitable for marketing, up to 12½ per cent. by weight of fine grit such as sharp-grained sand is added during the mixing process. Finally, the mastic is discharged from the tank and cast into flat blocks weighing approximately ½-cwt. each. It is thus in a convenient form for handling.

(b) *Artificial Asphalt* is a cheap and inferior substitute for the natural product. The composition is a mixture of *tar* with aggregates such as sand, pulverized chalk and *pitch* (see below). It is liable to deteriorate and become brittle. Therefore, when used as a damp proof course, cracks may appear through which water may penetrate. The composition of artificial asphalt varies, a common mixture being 1 part tar (or tar and pitch), 1 part sand and 1¼ parts crushed chalk. These are boiled in a tank and thoroughly incorporated by stirring before being run into blocks.

Tar, a black, thick, oily, strong-smelling liquid, is obtained by the destructive distillation in a closed retort of bituminous coal, wood and certain other organic substances.

Coal tar is the largest group, and is recovered as a by-product in gas manufacture. The gases produced when the coal in the retorts (long vertical or inclined vessels of circular or D-section) is heated proceed through the hydraulic main (a large pipe), condensers (pipes in which the gases are cooled), tar extractor and scrubbers (where ammonia and impurities are removed) to the gasometer. During the process, tar is deposited in the hydraulic main, condensers, extractor and scrubbers, collected and mixed.

Valuable oils are obtained by subjecting the tar to fractional distillation. The process consists of heating the tar in a still (metal cylinder) and collecting the condensed vapours. Benzene, toluene, naphtha, carbolic acid, cresol, creosote, naphthalene and anthracene are some of these oils.

Pitch is the residue in the still after the oils have been evaporated. This black coloured material has a variable consistency, becoming brittle in winter and softening when subjected to heat in the summer, hence the reason why this is an unreliable material for damp proofing (see above).

(c) *Fibrous Asphalt Felt* (see p. 18, Vol. I).—The continuous process is one of several used for manufacturing this material. The felt or hessian forming the base is passed in a continuous stretched sheet through a machine and successively (1) pre-heated as it travels over and under steam-heated cylinders, (2) impregnated with asphalt by being passed under and over a series of rollers in a tank containing hot liquid asphalt, (3) air-cooled as it traverses rollers, (4) passed through a second tank containing hot asphalt mastic and surface coatings of the liquid applied to each side of the sheet, (5) on emerging, sprayed by compressed air with grains of talc or similar material (to prevent the sheets from sticking together when coiled up) on the upper surface, (6) passed between a pair of rollers to embed the particles of talc and coiled by traversing air-

cooled drums, (7) automatically cut into 24-yd. lengths, and (8) finally wound into coils by a winding machine.

Application of Vertical Damp Proof Courses.—As stated on p. 17, Vol. I, the object of a horizontal damp proof course provided in a wall at least 6-in. above the ground level, is to intercept water absorbed from the soil and prevent it from rising up the wall. It is clear that this will not stop water from passing through a basement wall from the adjacent earth. Therefore it is necessary to introduce a vertical damp proof course which must extend from the above horizontal damp proof course down to a second horizontal course at or near the base of the wall.

Several alternative details showing the damp proofing of basements are illustrated in Fig. 20. A section through a basement is shown at A, in which a damp proof course in the thickness of the floor is continued vertically up each wall to the horizontal course placed at a minimum height of 6-in. above the ground level. The damp-resisting material thus forms a waterproof tank, preventing water from passing through the floor and walls adjacent to the earth, in addition to intercepting water absorbed from the ground which would otherwise pass up the walls above the ground level.

The damp proofing material in details B, C, D, E and G is natural asphalt mastic. The blocks of mastic (see p. 54) are broken into small pieces, placed into a tank on the site, and gradually heated until the asphalt is sufficiently fluid to be applied. With exception of detail E, the vertical damp proof courses are situated within the thickness of the walls, and thus conform with what is considered to be the best practice.

Detail C shows one method of damp proofing a basement which has a joist and boarded floor. The 1½-brick main wall has, in addition, a 4½-in. thick outer leaf which is finished with a plinth course. This leaf is built in stretching bond, and its function is to protect and retain the vertical damp proof course.

The wall is built up to the level of the lower damp proof course of asphalt or other approved materials described on pp. 17 and 18, Vol. I. It is constructed in the following manner: The main 1½-brick wall is continued for three or four courses, and the joints on the outer face are raked out to a depth of about ¾-in. to afford a key for the vertical asphalt. A similar number of courses of the outer leaf are built at a distance of ¾-in. from the main wall. This cavity is maintained and mortar droppings prevented from falling into it, if a length of 11-in. by ¾-in. board is placed next to the main wall as the leaf is constructed. This board is removed and the cavity is filled with molten asphalt from a pail; a length of floor board supported on the leaf by small splayed blocks and tilted towards the cavity facilitates this operation. A metal rod is used to consolidate the asphalt and prevent the formation of air voids. Care must be taken to ensure that the cavity is entirely free from mortar droppings before the asphalt is poured, otherwise water may be subsequently transmitted through such porous material to the main wall. The wall and vertical damp proof course are formed in short " lifts " in this manner until the position of the upper horizontal damp proof course is reached. The latter course is then applied and the normal construction of the wall continued.

Attention is drawn to the means of ventilation provided to safeguard the floor timbers against dry rot. Vertical shafts or flues, of 9-in. by 4½-in. cross section, are formed at approximately 6-ft. intervals in the centre of the main wall during construction; openings are left at the inner face below the basement floor, and the upper ends are completed with the usual perforated air bricks, as shown.

Detail D shows an alternative and efficient method of damp proofing. The bottom layer of concrete known as the *subfloor* is covered with a ¾-in. thickness of asphalt laid in two separate coats (or a 1⅛-in. thickness in three coats); this in turn is covered with a second layer of concrete, called the *loading floor* (as it counterbalances the upward pressure of subsoil water), and finished with wood block flooring (see p. 38, Vol. III).

The asphalt covering the subfloor is continued as a vertical damp proof course, additional asphalt being applied at the intersection between the horizontal and vertical layers, and finished as a splayed angle fillet, to prevent possible creep of moisture at the intersection. The vertical layer is formed as follows: The outer 4½-in. thickness of the wall is first constructed in stretching bond up to the level of the horizontal layer; the joints of the inner face are raked out and dust, etc., removed by means of a stiff broom; the first coat of the hot asphalt, approximately ⅜-in. thick, is then applied, it being spread or floated on by the aid of a *hand float* similiar to that shown at D, Fig. 23. The latter is applied with sufficient pressure until a smooth surfaced homogeneous layer of asphalt is obtained, free from voids or blow holes. Any blow holes must be stabbed, filled in and smoothed over. The second coat must cover the joints of the first. The finished thickness of two-coat work is ¾-in. For special work, and especially if water pressure has to be resisted, three separate coats are applied, the overall thickness being ⅞-in. or, preferably, 1⅛-in.

In order to provide a uniform backing for the asphalt, it is advisable to build the inner or main wall ¾-in. from the face of the asphalt. Grouted cement is run into this cavity as each four courses of the brickwork is built. If this is not done, spaces will be left between the asphalt and the outer face of the main wall, and any water from the soil forced through the outer leaf may seriously damage the unsupported patches of asphalt and gain entrance into the building. The cement grouted backing to the asphalt is shown in detail B.

The upper horizontal damp proof course may only cover the wall from the vertical layer to the outer face, or, preferably, extend for the full thickness of the wall as indicated by broken lines at D.

Sometimes the provision of subsoil drainage is made to remove the risk of damage to the vertical damp proof course. Thus, as shown at D, small diameter drain pipes (see Chapter Two) are laid butt-jointed in the trench and covered with about 2-ft. of gravel before the trench is filled in with soil. This subsoil drain is continued round

the building, laid with adequate fall, and continued to a hedge ditch or other suitable outlet. Hence the level of the subsoil water is lowered to that of the drain, eliminating pressure on the vertical damp proof course, as the water passes through the open joints of the drain and is removed.

Another form of internal vertical damp proof course is shown at G. The wall is constructed in two block-bonded thicknesses with a continuous double layer of asphalt between, the height of the blocks being five courses each.

The detail at E shows the vertical asphalt applied on the external face of the walls. The joints must be well raked out to afford an adequate key for the asphalt, otherwise there is a risk of the covering becoming detached from the wall. There should be a minimum width of 2-ft. 6-in. working space between the wall and the timbering of the trench to enable this to be done. In order that the asphalt will not be exposed to view and the hot rays of the sun, it is turned in 4½-in. just below the ground level and continued vertically to the upper horizontal course. This method is not so efficient as either of those shown at C, D and G, especially if the damp proof course is subjected to subsoil water pressure. The construction of the floor, in which Bull Dog clips are employed, is described on p. 38, Vol. III.

Detail F shows the application of sheets of fibrous asphalt felt. This bituminous sheeting is generally in 3-ft. widths and is laid vertically with 3-in. wide lapped joints. In the given example it is shown applied to the internal face of the main 1½-brick wall. This face is first rendered with cement mortar (1 : 3) of ⅜-in. thickness to provide an even surface for the sheeting.

It is usual for three men to work together when applying the felt. The roll is supported by two men holding the projecting ends of a wood roller which is passed through it. Commencing at the upper horizontal damp proof course previously laid, and working downwards, the underside of the roll as it is gradually uncoiled is heated by a blow lamp manipulated by the third man. Meanwhile, one of the other men holding an end of the rod with one hand, presses a hand float over the sheet as it uncoils and attaches it to the rendered face of the wall. This is continued, the roll being slowly uncoiled as it is heated and attached, until the base is reached. The upper edge must be thoroughly heated and *sealed* to the horizontal damp proof course, and the lower edge should be heated and lapped 3-in. over the floor damp proof course previously laid. Each successive vertical layer of sheeting must be thoroughly sealed by heat and pressure at the lapped joints.

The inner 4½-in. wall is built after the concrete loading floor has been formed, a ⅜ or ½-in. cavity being left between the leaf and the asphalt and filled with grouted cement as described on p. 55 in connection with detail B. It is usual for this inner leaf to be continued up to the basement ceiling.

Bituminous sheeting may also be applied next to a 4½-in. leaf as at D or externally as at E.

Damp Proofing of Floors.—The concrete floors shown at D, E, F and G are shown with a damp proof course over the concrete subfloor. Such provision is necessary if the site is damp (see waterproofed concrete floors on p. 57). The course may be either of asphalt mastic or fibrous asphalt felt.

The surface of the concrete must be absolutely dry before the asphalt is applied, otherwise adhesion will be adversely affected. It should be level and well brushed down. In order to promote adhesion, hot liquid asphalt, known as a *primer*, is brushed over the surface before the first coat of asphalt mastic is applied ; alternatively, the concrete may be covered with bituminous paper or *building paper* (one type consists of two layers of hemp impregnated with bitumen and covered with brown or kraft paper). This first coat of mastic, ⅜-in., thick, is spread and floated over in bays not exceeding 4-ft. 6-in. ; the joint between a bay and that last formed is properly sealed by spreading the hot asphalt some 3-in. over the edge of that already laid to soften it, and after the superfluous asphalt has been removed, the joint is well floated or ironed until both edges are properly bonded and levelled. The second coat is applied direct on to the first, care being taken that the joints do not coincide with those below. If a third coat is required, this must also break joint with the second.

If fibrous asphalt felt is to be used, as shown at F, the concrete subfloor is primed and the bituminous sheeting is laid with 3-in. lapped joints, as described in the preceding column for vertical sheeting, the sheets being heated as they are uncoiled and floated on to the floor. As any sharp projections on the surface of the subfloor may tear the sheeting, it is advisable to cover the concrete with a ½-in. thick layer of cement mortar. It is also desirable to cover the sheeting with a 1-in. layer of cement mortar to prevent damage when the concrete of the loaded floor is deposited. This also ensures a good backing for the damp proof course, which is very essential if water pressure has to be resisted.

In order to prevent damage being caused to the horizontal damp proof course by the upward pressure of subsoil water, it is often necessary to reinforce the concrete by a continuous layer of expanded metal or other steel reinforcement placed about 1-in. below the damp proof course. Similar reinforcement, placed approximately 1-in. from the top, is also usually provided in the concrete loading floor. Such reinforcement resists the tension stresses created.[1] In all such construction the loading floors should be tied or built-in to the walls, as shown at D, E, F and G.

Treatment of Damp Existing Basement Walls.—The absence of vertical damp proof courses is a frequent cause of dampness in walls of existing basements.

One method of curing such dampness is to apply a bituminous sheeting vertical damp proof course to the internal face of the wall, similar to that shown at F and described in the preceding column, and to construct a 4½-in. brick (or concrete) wall from the floor to the ceiling.

Alternately, asphalt mastic may be applied to the internal faces of the walls after any plaster has been removed and the joints well raked out. Two coats of asphalt may be rendered as described in connection with detail D and a 4½-in. brick lining constructed, or this inner lining may be built with a ¾-in. cavity between, into which the liquid mastic is poured (see description on p. 55 in respect to detail C). If a wall exceeds 9-ft. in height, it is desirable to bond the new 4½-in. brick lining to it ; this is effected by forming 5-in. by 5-in. by 4-in. high pockets (one per square yard) in the existing wall, lining these with asphalt mastic, and building in headers from the new wall during its construction.

If the wall can be treated externally, the vertical asphalt damp proof course may be applied on the outer face, as shown at E.

When the floor, in addition to the walls, of an existing basement is damp, it is advisable to take up the floor, replace it with at least 6-in. thickness of concrete (1 : 2 : 4) and cover it with a ¾-in. double layer of *coloured asphalt* before the walls are treated. This can be obtained in various colours, and provides a noiseless, damp-resisting and hygienic finish. Occasionally the layer of asphalt

[1] See Vol. IV.

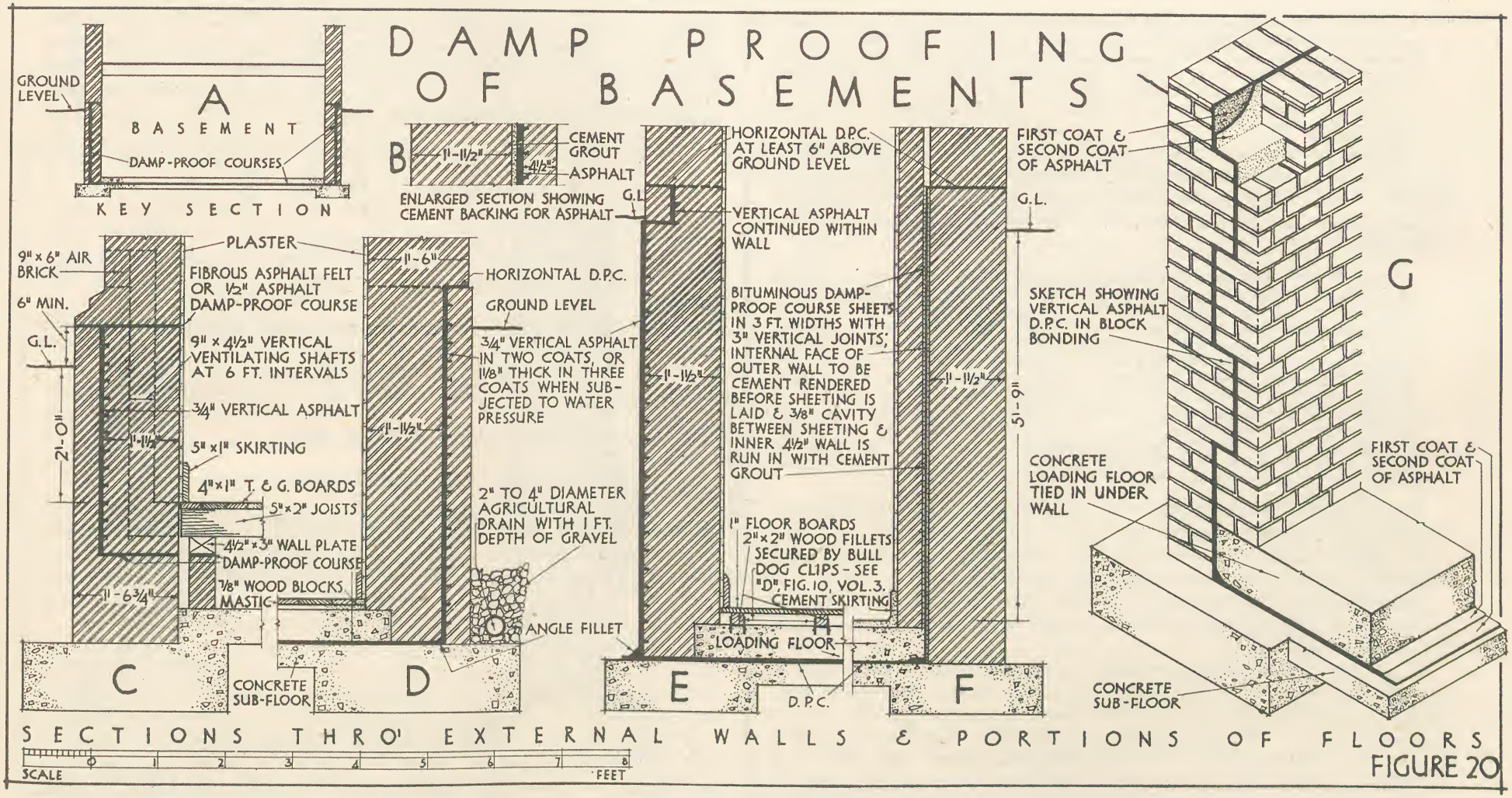

DAMP PROOFING OF BASEMENTS
GROUND LEVEL
A
BASEMENT
DAMP-PROOF COURSES
KEY SECTION
B
1'-1½"
CEMENT GROUT
4½"
ASPHALT
ENLARGED SECTION SHOWING CEMENT BACKING FOR ASPHALT
9" x 6" AIR BRICK
6" MIN.
G.L.
21'-0"
PLASTER
FIBROUS ASPHALT FELT OR ½" ASPHALT DAMP-PROOF COURSE
9" x 4½" VERTICAL VENTILATING SHAFTS AT 6 FT. INTERVALS
¾" VERTICAL ASPHALT
1'-1½"
5" x 1" SKIRTING
4" x 1" T. & G. BOARDS
5" x 2" JOISTS
4½" x 3" WALL PLATE
DAMP-PROOF COURSE
⅞" WOOD BLOCKS MASTIC
1'-6¾"
C
CONCRETE SUB-FLOOR
1'-6"
HORIZONTAL D.P.C.
GROUND LEVEL
¾" VERTICAL ASPHALT IN TWO COATS, OR 1⅛" THICK IN THREE COATS WHEN SUBJECTED TO WATER PRESSURE
1'-1½"
2" TO 4" DIAMETER AGRICULTURAL DRAIN WITH 1 FT. DEPTH OF GRAVEL
ANGLE FILLET
D
HORIZONTAL D.P.C. AT LEAST 6" ABOVE GROUND LEVEL
G.L.
VERTICAL ASPHALT CONTINUED WITHIN WALL
BITUMINOUS DAMP-PROOF COURSE SHEETS IN 3 FT. WIDTHS WITH 3" VERTICAL JOINTS; INTERNAL FACE OF OUTER WALL TO BE CEMENT RENDERED BEFORE SHEETING IS LAID & 3/8" CAVITY BETWEEN SHEETING & INNER 4½" WALL IS RUN IN WITH CEMENT GROUT
1'-1½"
1" FLOOR BOARDS 2" x 2" WOOD FILLETS SECURED BY BULL DOG CLIPS - SEE "D", FIG. 10, VOL. 3.
CEMENT SKIRTING
LOADING FLOOR
D.P.C.
E
F
FIRST COAT & SECOND COAT OF ASPHALT
G.L.
51'-9"
SKETCH SHOWING VERTICAL ASPHALT D.P.C. IN BLOCK BONDING
CONCRETE LOADING FLOOR TIED IN UNDER WALL
FIRST COAT & SECOND COAT OF ASPHALT
CONCRETE SUB-FLOOR
G
SECTIONS THRO' EXTERNAL WALLS & PORTIONS OF FLOORS
SCALE
0 1 2 3 4 5 6 7 8
FEET

FIGURE 20

may be placed direct upon the existing concrete floor ; this is rarely satisfactory, as the concrete is usually defective.

Waterproofed cement (see below) is also applied to walls and floors of damp existing basements in lieu of bituminous materials.

2. Waterproofed Cement Renderings and Concrete.—Waterproofers, as described on p. 27, are used for cement renderings and concrete (see p. 36) for damp proofing basements. The composition of the mixes varies according to the waterproofer, water pressure (if any) to be resisted, and the particular requirements of the building. In all cases the directions of the proprietors of the waterproofers should be complied with, and only best materials and workmanship employed.

The construction may be somewhat similar to that shown at E, except that the floor consists of one layer only of waterproofed reinforced concrete covered with a rendering of waterproofed cement mixture ; the rendering is continued vertically on the outer face of the wall to the upper horizontal damp proof course as shown.

The composition of the concrete recommended by one firm whose product is a well-known waterproofer in powder form is 1 part Portland cement, 2 parts

sand, 3 parts coarse aggregate (graded from ¾-in. down to ¼-in.) and 3-lb. of waterproofer to 100-lb. of cement. The reinforcement is placed at 1-in. from the upper surface, the thickness of the floor and amount of reinforcement depending upon the span and water pressure to be resisted. The concrete is at once covered with a ¾-in. mixture composed of 1 part Portland cement, 2 parts sand and 5-lb. of waterproofer to 100-lb. of cement. The vertical rendering is of similar composition, but is 1-in. thick in three coats.

To cure dampness in an existing basement, it is recommended that a 6-in. layer of waterproofed reinforced concrete, composed as above, be formed on the old concrete floor; this is rendered with a ¾-in. layer of waterproofed cement mortar, as above, and continued as a 1-in. thick vertical layer on the inner face of the walls.

The following is the sequence of operations: (1) Chases are formed in the walls to receive the edges of the waterproofed concrete floor; (2) any plaster, limewash or paint is removed from the walls, the joints are raked out or the brickwork (or stonework) is hacked over by using a hammer and punch to give a key for the rendering, the walls are brushed down with a stiff broom to remove dust and afterwards copiously watered to prevent excessive absorption of moisture from the rendering; (3) the surface of the existing floor is well hacked, brushed and washed; (4) a 5 per cent. grout of waterproofed cement is brushed over the cleaned surface to effect a bond between it and the waterproofed concrete layer which is at once laid before the grout sets; (5) this is rendered without delay; (6) each prepared internal face of the wall is grouted, and after the fillet has been carefully formed at the bottom corner (this is important, as the intersection is vulnerable) and before the grout has set, the first coat of the wall rendering is applied, followed by the subsequent coats.

Defects in this form of damp proofing may occur through cracks which may develop in the rendering coats through which water may penetrate.

In modern construction, basements are frequently constructed of solid reinforced concrete walls, the concrete being waterproofed.

A double course of slates, bedded in cement (as described on p. 18, Vol. I), may be used as a cheap, but less effective, alternative vertical damp proof course to those described above.

Finally, the practice adopted in cheap work of rendering the *inside* faces of basement walls with two coats of cement mortar to a finished thickness of ¾-in. is highly undesirable, as dampness will ultimately appear through this thin unwaterproofed layer. The covering of damp walls with wood *cleading* or panelling should also be discouraged, as this only hides the defects, and, whilst the unhealthy conditions still remain, the wood is likely to be attacked by dry rot.

The provision made for damp proofing walls built on sloping sites is described on p. 60.

Dry or Open Areas.—Fig. 21 shows a section through a typical open area. Such provision is necessary to afford natural lighting and direct access to a basement.

The ground is supported by a *retaining wall* some distance from the outer wall of the building. The area must be paved and drained, gullies (see p. 72) being placed as required and connected by drains to the public sewer. The retaining wall must be built in cement mortar, and is usually surmounted by a metal railing or balustrade, as this obstructs little light; either small *weep-holes* must be formed, or pipes, as shown, provided near the base of the wall to allow the escape of subsoil water, otherwise the pressure may overturn it, especially if the water becomes frozen. The floor of the basement is an alternative to those shown in Fig. 20; if the ground is waterlogged the concrete must be waterproofed and reinforced as described on p. 56.

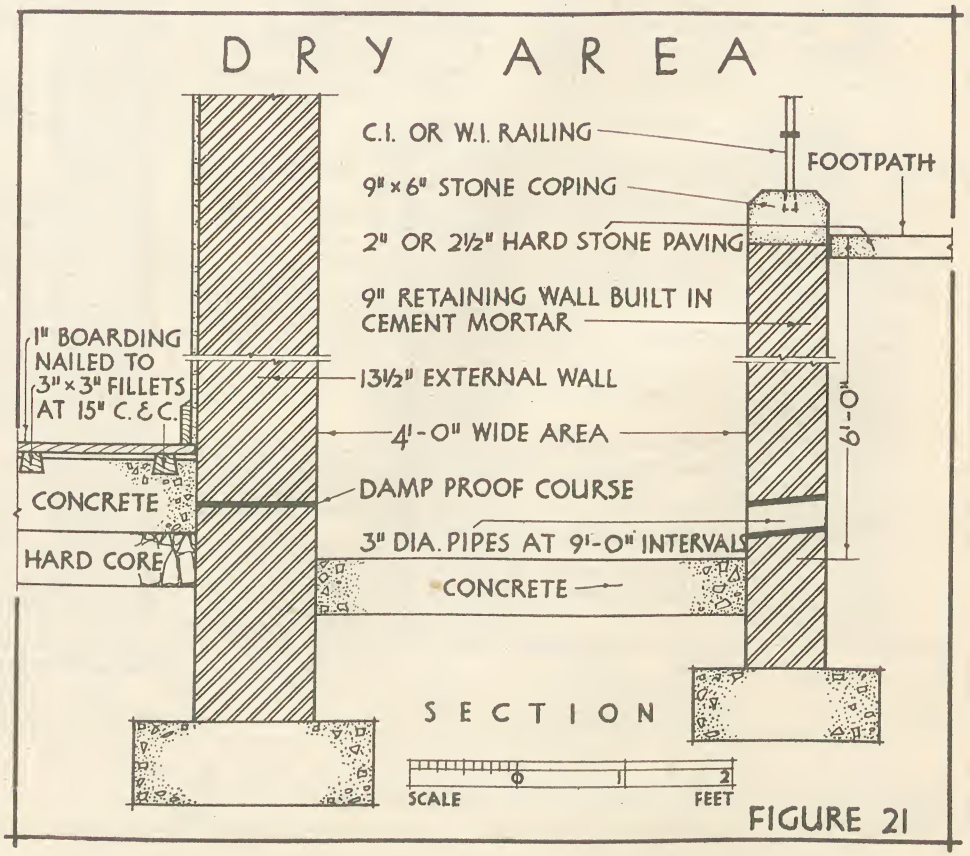


FIGURE 21

A *closed dry area* may consist of a 4½-in. independent wall, extending from a few inches below the basement floor to the ground level, 2¼ to 4½-in. from the main wall and finished at the ground level with a brick-on-edge coping which closes the cavity; the latter may be ventilated by vertical shafts formed in the main wall, similar to that shown at C, Fig. 20. This is an undesirable form of construction, as water may gain access through the thin retaining wall and cause dampness as it accumulates. To overcome this defect the closed cavity is sometimes increased in width, the bottom is concreted and a gully provided which is connected to the sewer by a drain. This gully will, however, become unsealed (see Chapter Two) in dry weather owing to the evaporation of the water in the trap, and thus gases from the sewer will escape into the inaccessible cavity. Such provision cannot be too strongly condemned.

STEPPED FOUNDATIONS FOR SLOPING SITES

Foundations must be horizontal irrespective of the character of the site. If a site has little or no fall, the foundations of walls of the same thickness are generally level throughout. On a sloping site, however, it would be uneconomical to construct all foundations at the same level as that of the lowest, and it is therefore the practice on such a site to arrange the foundations at different levels according to the slope. Such are known as stepped foundations. The steps should be in relatively short lengths and preferably of uniform height not exceeding 3-ft., the smaller the better. Hence when the slope is considerable, it is desirable to form the foundation of a wall of appreciable length in a series of small steps ; if the steps are high owing to their inadequate number, there is a risk of unequal settlement occurring due to the large variation in the loads transmitted to the foundation on each side of a benching (see below) and the difference in shrinkage of the mortar joints between the larger number below each benching and those above ; this may cause cracks to appear in the wall immediately over the changes of depth. The lengths of the steps need not be uniform, and they may vary considerably if the fall is very irregular.

Two typical arrangements of stepped foundations are shown at A and B, Fig. 22.

The site at A has a fairly regular slope, with a total difference in level in the length of the wall of 4-ft. The two steps are of uniform height. The sketch detail C shows the concrete continued vertically from the lower to the upper concrete beds. This is known as a *benching* and should be of a width at least equal to the thickness of the concrete bed. In this example the floor level is the same throughout.

The sectional elevation at B shows the ground to have an irregular fall, the total difference in level being 7-ft. Advantage has been taken of the fall to obtain garage accommodation as shown ; a building should be designed to obtain accommodation in this manner in order to reduce the cost and avoid " dead walling " at the lower level. The foundation consists of brick footings on concrete as an alternative to that at A. The detail at D shows the footings (and wall) of the lower section abutting against the concrete benching, and those above it returned, the lowest course of footings being 6-in. from the edge of the benching.

Site Concrete.—This has not been shown in order to avoid complication. No attempt would be made to arrange this in a series of level steps ; the top 6-in. of virgin soil would be removed and the 6-in. of site concrete would be formed to a slope more or less conforming to that of the ground. The floor of the garage at B would be of concrete. The site concrete under the floor on the left of the division wall could be laid to fall as described above, in which case the division wall would require a vertical damp proof course ; alternatively the latter can be dispensed with if the earth is excavated to a depth of 9-in. below

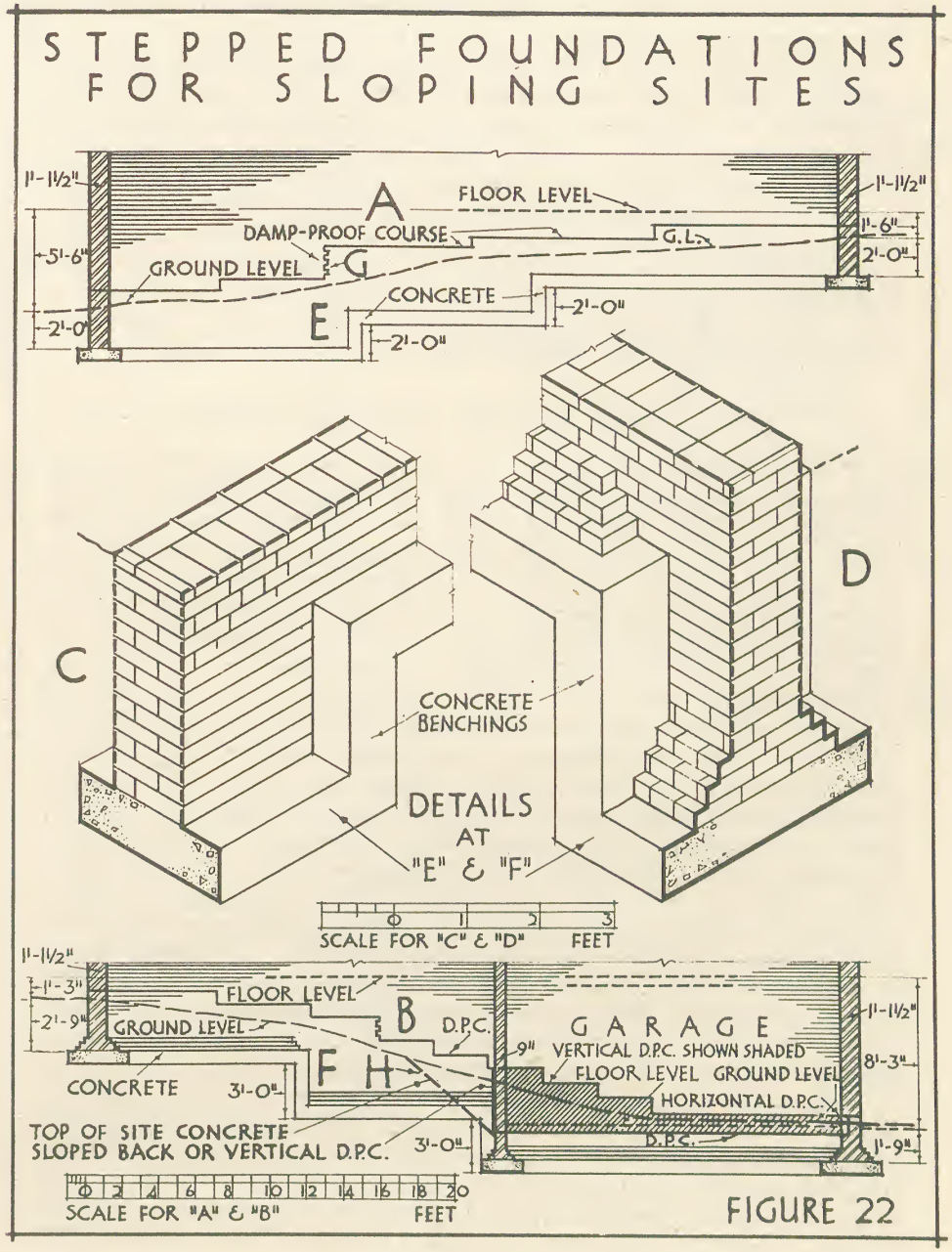


FIGURE 22

the horizontal damp proof course in the wall, sloped back and covered with 6-in. of site concrete as shown at H.

DAMP PROOFING.—The horizontal damp proof courses are stepped as shown, care being taken that none come within 6-in. of the ground ; the vertical joints should be as short as possible in order not to weaken the walls, otherwise the steps should be as shown at G where asphalt mastic is applied and the adjacent walling toothed. A vertical damp proof course, indicated by a thick line, would be required on the back face of the garage division wall unless the earth is removed and the site concrete sloped as explained above. The vertical damp proof course is required to be continued round the side walls of the garage as the floor is below the ground level ; this may be applied to the internal faces, as shown by the shaded area, but if this is objected to on the score of appearance, it may be formed within the thickness of the wall in the usual manner.

CONCRETE FLOOR CONSTRUCTION

A concrete floor may consist of a single layer, known as *one-course work*, or two layers called *two-course work*. The former is commonly adopted for floors of garages, cellars, coal houses, etc., and those which are to be covered with other materials such as boarding and asphalt ; site concrete is in one layer only. Two-course work is generally employed in good practice, and consists of a base layer covered by a finishing surface or wearing coat which should not be less than $\frac{3}{4}$-in. thick. A common mix for the base is 1-cwt. Portland cement, $2\frac{1}{2}$-cub. ft. of clean coarse sand and 5-cub. ft. of coarse aggregate graded 1-in. down to $\frac{5}{16}$-in. (producing a 1 : 2 : 4 mix, see p. 30); just sufficient water should be used to give a 2-in. slump. A hard wearing surface, known as a *granolithic* finish, is obtained from a mixture of 1 part cement, 1 part sand and 2 to 3 parts clean granite or whinstone chippings (crushed granite) capable of passing through a $\frac{1}{4}$-in. square mesh sieve and excluding dust ; approximately 60 per cent. of the chippings should be retained on a $\frac{1}{8}$-in. mesh sieve ; the surface concrete should give a 1-in. slump (see p. 31). The concrete is either machine or hand mixed, as described on p. 34. An excess of water, cement and trowelling (see below) should be avoided, as this brings the cement to the surface and produces what is known as a dusty floor. The surface should be applied to the base before the latter has hardened. The ground should be firm, any soft patches being replaced with concrete or hard stone. Sometimes a 6 to 12-in. layer of broken bricks or stone is first laid to receive the base layer ; this sub-base is called *hard core* or *penning* (see Fig. 21).

Methods of forming a Concrete Floor.—Large floors are formed in a series of bays or sections, a convenient size being 10-ft. square, concreted alternately. One of several methods of forming a two-coursed floor is as follows : As shown at A, Fig. 23, $1\frac{1}{2}$-in. thick *edge-boards* or battens are nailed to wood stakes (or secured by staples to $\frac{3}{4}$-in. diameter metal rods) driven in along the boundaries of the bays at about 4-ft. centres, the top edges of the battens being brought to the required floor level by the use of a long straight edge and spirit level. The base concrete is deposited in a bay, spread, and shovelled up to a height slightly more than the finished level. A wood *strike-board*, *tamper*, or *striking-off board* is then used to consolidate and bring the concrete to a uniformly level surface ; as shown at B, this strike-board is notched at each end, the depth of the notch being equal to the thickness of the surface coat of the floor. It is manipulated by a man at each end who, working together, tamp down the concrete by lifting and releasing it as they proceed slowly backwards and forwards, any excess concrete being struck off as the tamper is brought forward when traversing the battens, and any low patches being filled in before the surface is given a final light tamping.

The wearing coat should be laid within an hour of mixing the base concrete. The ends of the strike-board used for forming the finishing coat are not notched (see C). The granolithic mixture (see preceding column) is deposited and then levelled as the strike-board is caused to traverse the edge-boards with a to-and-fro and zigzag motion. When sufficiently hard, the surface is tamped and floated with the wood *float* D, any irregularities being made good. The surface is finally trowelled smooth by means of the *steel trowel* E, which is worked in a circular motion. Excessive trowelling brings to the surface a liquid scum, called *laitance*. Such should be avoided, as this destroys the initial set and produces a friable, non-wearing surface having a glossy finish which has a tendency to dust and craze.

Not all surfaces are finished in this manner. Thus, for common work, the concrete is often *spade-finished*, *i.e.*, the surface is beaten down and smoothed over with the back of the spade. Another finish, often adopted for paths and roads, is produced by jumping the strike-board up and down as it traverses the edge-boards, to form a serious of small corrugations. A hard-wearing surface of attractive appearance may be produced by mechanically operated grinding discs which are applied to the floor after it has become sufficiently hard. This exposes and polishes the coarse aggregate.

Terrazzo is another finish used in first-class work. One method is to cover the concrete base with a 1-in. thick wearing coat composed of 1 part cement and 2 parts sand ; crushed marble of $\frac{1}{4}$-in. gauge (free from dust) is sprinkled and rolled into this coat whilst it is still soft ; when sufficiently hard (three or four days after laying) it is ground down to a smooth surface by stone discs mechanically operated. Another terrazzo finish consists of a 1-in. coat of 1 part cement and $2\frac{1}{2}$ parts crushed marble of $\frac{1}{2}$-in. gauge or less, which is machine ground after it has been allowed to partially harden.

An alternative method of forming a two-course floor is as follows : The floor is divided into bays, as above described, by temporarily bedding wood battens, called *screed rules*, on narrow strips of concrete ; these are firmly tapped in position until their top edges are brought to the required level by means of a straight edge and spirit level ; each alternate bay is dealt with in turn ; the base concrete is deposited and levelled off to the top of the screeds by a straight edge which is drawn over them in a zigzag manner ; the concrete is compacted or *punned* with a *wood rammer* (see F) or *iron rammer* or *punner* (see G) ; the top layer of concrete is then spread over the base, brought to a level surface flush with the screeds by means of the straight edge, floated (D) and trowelled (E) as already described ; the screeds are removed, and the holes filled in with concrete and levelled off.

The floor should be covered with damp sacks or 2-in. thickness of sand, kept moist by occasionally spraying water on it from a hose to prevent the concrete from drying out too rapidly. It should be kept damp for at least ten days (see p. 35).

CONCRETE FLOOR CONSTRUCTION

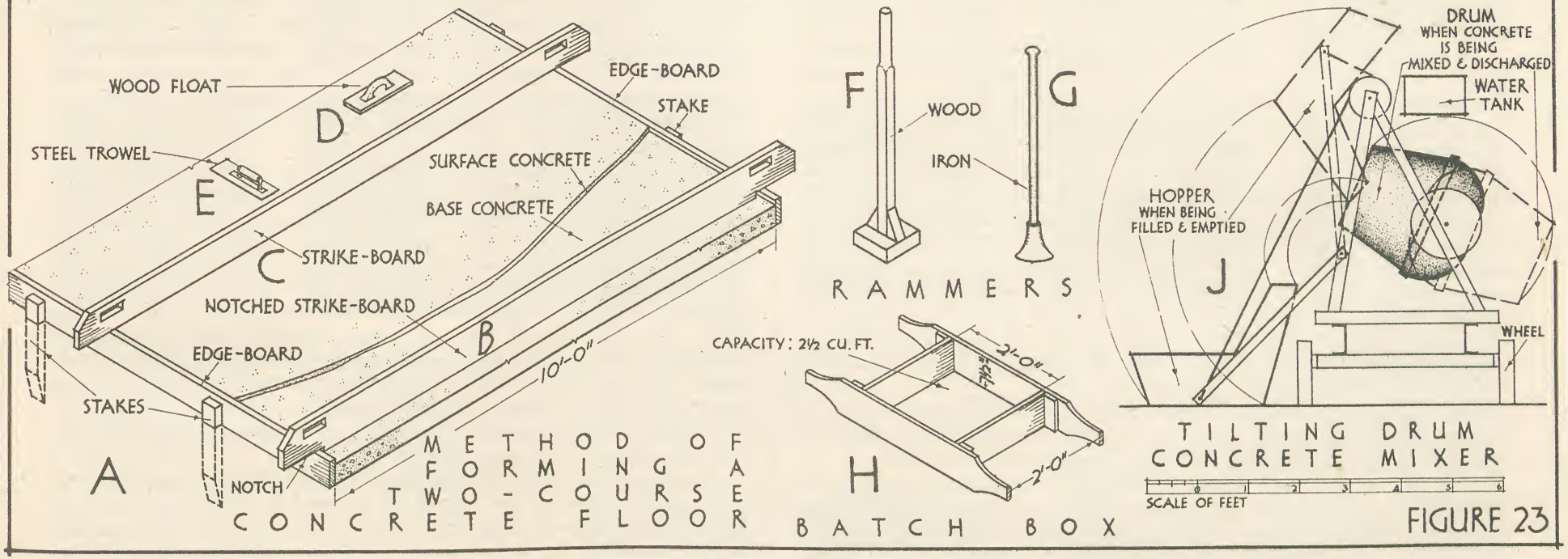


FIGURE 23

DECORATED BRICKWORK

The decorative value of brickwork is influenced by the size, shape, colour and texture of the bricks and mortar joints, in addition to the face arrangement of the bricks and form of the feature.

Bricks.—The thickness of the bricks affects the appearance of faced brickwork considerably. Whilst a wall built of thick bricks looks strong, and these are therefore suitable for engineering work, it is generally agreed that the appearance of most walls is enhanced if 2-in. bricks are employed. Bricks which are uniform in shape, with straight, sharp arrises, give a mechanical appearance to a wall, which is avoided by the use of the somewhat irregularly edged and surfaced hand-made variety.

A wide range of colours and textures of bricks is now available (see pp. 12 and 13). Some walls are purposely built of bricks which are uniform in colour ; such bricks must be carefully selected if a dull, monotonous appearance is to be avoided. Within recent years there has been an increased demand for multi-coloured bricks ; these have a very pleasing appearance, provided the selected shades suitably blend and violent contrasts are avoided. Regarding texture, bricks having a smooth surface can be readily cleaned and are therefore often employed for external walling in towns where they quickly become discoloured in the dust-laden atmosphere ; otherwise sand-faced or richly textured bricks are generally preferred because of the excellent effect they produce.

Jointing and Pointing.—Particular attention should be given to the colour of the mortar, and the shape and texture of the joints used for facing work. Various forms of jointing and pointing are described on pp. 31 and 32, Vol. I. The appearance of a wall constructed of sound materials and workmanship may be completely ruined by the adoption of unsuitable joints. Thus, for example, joints least suitable for sand-faced bricks of rich texture and warm colouring are those of black or dark blue mortar (see p. 27) which are struck-jointed, on account of the colour and the *smooth* mechanical appearance.

The texture of the joints should conform with that of the bricks. Joints smoothed over with the trowel should not be associated with rough textured bricks, for which flush and recessed joints (see Vol. I) give the best results. If neither of the latter can be adopted because of expense, a satisfactory finish to

rustic brickwork is obtained if the joints are just left as the mortar is cut off with the trowel, no attempt being made to smooth the surface ; the fairly rough texture of such joints gives a more satisfactory finish to this class of work than that produced by smooth struck joints.

The colour of mortar is referred to on p. 27, to which attention is drawn. Marked contrasts between the colour of the jointing material and the bricks should be avoided, hence white joints should not be used with bright red facings. Generally, black mortar should be avoided for faced work. The design of a façade can be influenced by mortar joints ; thus, horizontality can be effectively stressed if the vertical joints are made inconspicuous by flush-pointing them with mortar of the same colour as that of the bricks (which should be uniform), and a lighter coloured mortar is used for the flush-pointed bed joints.

That the shape of the joint affects the appearance of brick walling may be appreciated by comparing work which has been flush jointed and that with recessed joints. Whilst both are attractive, there is a big contrast between the flat appearance of the former and the deep shadows formed by the latter, in which each brick unit in the mass is clearly defined. An effective modification, in which both of these joints may be employed in conjunction, consists of flush vertical joints and recessed bed joints.

The thickness of the joints is also important. With few exceptions, such as for glazed brickwork, thin joints should be avoided. Most first-class work has $\frac{3}{8}$-in. thick bed joints, and sometimes this thickness is increased to $\frac{1}{2}$-in.

Monotony of plain brick walling is relieved by using bricks either of contrasting colour, or texture or face appearance, or a combination of all three, at prominent positions, such as at parapets, quoins, string courses, door and window openings, etc. The judicious use of stone and tiles at these positions assists in providing interesting contrasts. A few examples of these are illustrated in Fig. 24.

Parapets (see A, B, C, D, E and F).—That at A shows a simple finish to the quoin of a brick-on-edge parapet. The double course of tiles at B is surmounted by brick-on-end and brick-on-edge courses, both of which may be set slightly back from the face and at the quoin. The parapet course at C consists of stretchers alternating and coursing with bricks laid on end bed-faced ; this is bedded on a slightly projecting stretching course and is finished with one or more projecting courses of tiles. Bricks-on-end (which may be slightly set back from the face), surmounted by two courses of thick tiles, comprise the parapet at D, and an interesting finish at the quoin is provided by the tiles as shown. A simple but effective detail is shown at E, where the top four heading courses are set back (or *indented*) $\frac{1}{2}$ to 1-in. from the face and at the quoin, and these alternate with stretching courses of suitable contrasting colour flush with the wall face ; a 2-in. thick stone coping serves as a finish. That at F simply consists of a brick-on-edge course surmounted by a similar stone coping.

Additional designs suitable for parapets, modified as required, include the string courses at N.7, 8 and 9, diagonal pattern at M.1 (or a course of bricks laid diagonally), herring-bone pattern at M.2 (two inclined courses laid horizontally), pattern M.3 (see below), pattern M.5 (arranged horizontally), bricks-on-end as shown at P.10, and one or more courses of basketweave shown at P.14.

The top courses of bricks, tiles or stone of a parapet should be well bedded and jointed in cement mortar in order to exclude water and increase stability. The provision of a horizontal damp proof course, below the parapet and extending the full thickness of the wall, is an additional requirement.

Built-up cornices, involving the use of moulded bricks, rarely find a place in modern design.

Quoins (see G, H, J, K and L).—Additional interest may be provided by simply using at the quoins bricks of contrasting colour to that of the rest of the walling, and producing a toothed effect, as at G and L ; the quoin bricks may be darker than the adjacent walling (*i.e.*, " purple " quoins against a mass of " buff brindles ") or lighter, such as " cherry red " quoins contrasting with " dark strawberry " coloured adjoining brickwork. The appearance of additional strength is obtained by using rusticated or indented quoins, as shown at H, J and K. The elevation and sketch at H show projecting blocks of two-course depth alternating with three-course projecting blocks, the blocks being of uniform length. The treatment at J is somewhat similar, but the shorter alternate blocks give a toothed effect. Projecting blocks at greater intervals are shown at K.

In general, indented courses should not have a greater set-back than 1-in., if a coarse appearance is to be avoided.

This form of treatment is also employed at door and window openings.

String Courses.—A few suggestions are shown at N.6, 7, 8 and 9, and at J. Most of the parapets described above may also be adopted for string courses or friezes. Moulded brick courses are not now greatly favoured.

Panels.—Large masses of plain walling may be relieved by the provision of decorative panels. A few designs are shown at M.1, 2, 3, 4 and 5. That at M.1 shows square panels of bricks laid diagonally with header divisions ; the infilling bricks may be of contrasting colour. The panel at M.2 consists of a herring-bone infilling, short brick-on-end head and sill, and header verticals. Panel M.3 comprises three " piers " of purpose-made bricks with bevelled faces which project (see plan), alternating with bricks arranged on end, and finished with two courses of tiles top and bottom, the latter projecting as shown on plan. The simple rectangular panel at M.4 projects (see plan) and is of contrasting colour. A somewhat complicated design, suitable for a large panel, is shown at M.5 ; such provides an interesting feature, especially if surrounded by a large mass of brickwork ; the panel may be given a slight projection. Another form of panel, much favoured, consists of an infilling of bricks arranged in basketweave pattern (see P.14).

Arches.—Apart from their design, arches may emphasize such salient features as doors and windows by the employment of bricks of contrasting colours and textures, and the introduction of differing materials forming the keys and imposts. Thus, for example, a pleasing effect to a façade constructed of dark coloured

DECORATED BRICKWORK

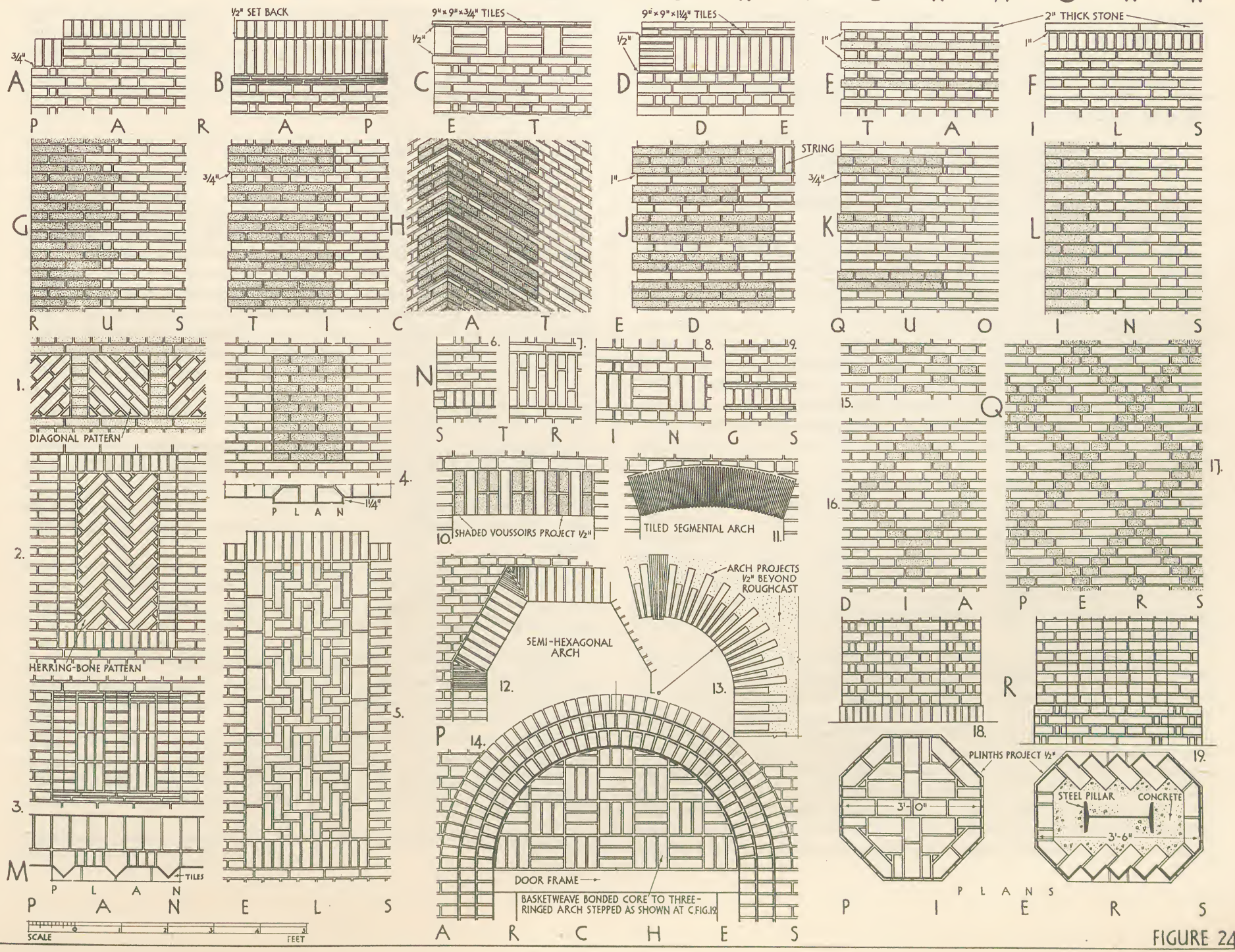


FIGURE 24

bricks may be obtained if rubbers or similar coloured voussoirs are used for the arches, and points of interest provided if tiles or stone are used for key blocks.

Several arches having tiled keys are shown in Vol. I and in Fig. 19 of this volume; additional examples are illustrated in Fig. 24. That shown at P.10 shows a lintel or soldier arch with several projecting voussoirs. P.11 shows a segmental arch constructed entirely of tiles.

The mortar joints at the tiled soffit (and sometimes on the face) are usually recessed (see P.11). This effect is obtained by spreading a ¾-in. layer of sand on the wood centre; each tile is forced down until it touches the lagging, and mortar is spread on the bed of the tile above the sand. Pointing is applied on removal of the centre. This ensures clean exposed edges of the tiles, which are otherwise liable to become stained with the mortar and rendered inconspicuous.

The semi-hexagonal arch at P.12 embodies tiles at the corners. The semi-circular arch P.13 consists of a tiled key block and purpose-made long voussoirs alternating with shorter ones; this toothed arrangement is continued down the jambs; owing to the difficulty in accurately cutting to the required shape the bricks adjacent to the extrados, this form of arch is usually associated with rough-casted walls, and rough cutting is therefore only necessary. A semi-circular arch, with stepped rings, over a door opening is shown at P.14; the core or tympanum is filled with bricks arranged in basketweave pattern; an equally effective treatment is to arrange the bricks forming the core in herring-bone formation. This core is supported on a stout oak frame, and one or more courses of tiles (with ½-in. projection) are often introduced between the top of the frame and the brickwork.

Diaper Work.—Variegated coloured or diaper work in which dark coloured bricks, arranged in pattern form, are associated with lighter coloured brickwork (or light coloured brick patterns contrasting with general walling of dark bricks) is less prevalent in modern construction than formerly. The present tendency, when multi-coloured bricks are employed, is to lay the " darks " in haphazard fashion, no attempt being made to arrange them to any mechanical pattern.

A few examples of diapers or chequer work are shown at Q.15, 16 and 17. In each case the general wall bond is adjusted to suit the particular design of the diapers.

Piers.—These have been referred to on p. 40. The detached octagonal pier shown in plan and part elevation at R.18, with a simple brick-on-edge plinth having a ½-in. projection, has a pleasing appearance. Indented courses, set back about ¾-in. and at six to eight course intervals, are sometimes provided in this form of structure. An alternative design (occasionally employed in modern churches) is shown in plan and part elevation at R.19. Steel pillars (which support the steel roof trusses and any steel beams) are encased in concrete and finished with brickwork. The plinth is four courses high above the floor and has a ½-in. projection. The bricks forming the two longer faces of the pillar shaft are arranged diagonally (those in alternate courses being laid in the opposite direction) to give a serrated effect. As shown, these bricks are not purpose-made; special bricks, shaped somewhat like those indicated at M.3, are sometimes used. The concrete is placed in position as the brickwork proceeds. Although this brickwork does not support any load, other than its own weight, it is advisable to tie the shorter faces into the concrete by placing 1-in. by ¼-in. by 6-in. long copper strips in the bed joints at sixth course intervals.

FIREPLACES, FLUES, CHIMNEY BREASTS AND STACKS[1]

As a means of heating a living-room of a house the open fire is still the most popular in this country, despite the fact that it is very largely responsible for the pollution of the atmosphere by the smoke and other products of combustion emitted from it. It also serves as one of the most effective aids to natural ventilation. Incidentally, a convenient and cheap supply of hot water for domestic purposes is obtained if the fireplace accommodates a copper boiler associated with a range, the more modern of which is economical in fuel consumption. In districts where cheap supplies of electricity (or gas) are available, the present tendency is to use radiators as a sole means of heating bedrooms and dining-rooms, and thus the provision of open fireplaces in such rooms is not necessary.

Each open fireplace must be provided with a *flue* or duct for the removal of smoke. If the chimney in which the fireplace opening and flue are formed projects (and it generally does) it is known as a *chimney breast* until it penetrates the roof, when it is called a *chimney stack.*

Fireplace, etc., construction must comply with the bye-laws. The requirements of the Model Bye-laws, reprinted in 1939, have been briefly incorporated in the following description, and most of them are illustrated in Fig. 25. This shows the plan B, vertical section C and elevation A of a two-storied chimney breast (which accommodates two fireplaces and flues), together with enlarged details.

Foundations.—The foundations of a chimney must be similar to those of the adjacent wall, *i.e.*, they must comply with either of those shown at A, B or C, Fig. 10, Vol. I (see A, C and Z, Fig. 25). The chimney must be well bonded to the adjacent wall (see plan at Z) and be provided with a proper damp proof course (see A and section at Z).

Chimney Breast.—The *jambs* (attached piers at the sides of a fireplace opening) must be not less than 8½-in. wide. Their projection varies according to the type of range to be accommodated, thus a greater projection is required for a kitchen range than for most bedroom fireplaces. The size of fireplace opening also varies, thus a modern kitchen range (with oven) of medium size will require an opening 3-ft. 6-in. wide by 4-ft. high, whilst the smallest bedroom fireplace opening need only be 1-ft. 6-in. wide and 2-ft. high. The width of a chimney breast may be varied according to the size and importance of a room,

[1] The introduction to fireplace construction is sometimes deferred until the third year of the course.

thus, for a long drawing-room, the breast may be at least 6-ft. wide in order that it may be of suitable proportions.

The *head* of a fireplace opening is finished with either a stone or concrete lintel or a brick arch, the latter usually being segmental in two rough rings. Where a breast projects more than 4½-in. and the jambs are less than 13-in. wide, a brick arch must be built on a wrought iron or steel bar, 9-in. longer than the opening at each end, with ends turned up and down ; the ends may be split and turned as shown in Fig. 26, or turned either up or down without being split ; the object of this *cambered chimney bar* is to tie in the narrow abutments.

The *back* of a fireplace opening in an *external* wall (see B and Q) or between two openings built *back-to-back* (see R) in a wall, *other than* a *party wall*, shall be at least 4-in. thick. A party wall is a division wall between two buildings occupied by different tenants or belonging to different owners. The back of every other opening (thus including a single opening in an *internal* wall as at S, and back-to-back openings in a party wall) shall be not less than 8½-in. thick. The backs shall be continued at the thickness stated for a height of at least 12-in. above the top of the opening, unless the opening is in a party wall and is for a kitchen range when the thickness (8½-in.) must be continued for a height of 9-ft. above the level of the hearth.

FLUES.—The size of a flue is usually 9-in. by 9-in. and this should be uniform through its length, except at its outlet, where it may be slightly restricted. The brickwork above the fireplace opening is corbelled or *gathered over* in order to reduce the opening to the size of the flue and avoid a large space which may produce eddies and reduce the upward current (draught) of the flue (see A, Figs. 25 and 26). This reduced opening is known as a *throat*. The two flues at A, Fig. 25, are indicated by broken lines (see also C). That from the lower fireplace must be bent in order to negotiate the upper fireplace. The gathering over should be arranged to bring the narrowest part of the throat centrally over the fire, not as shown at C, Fig. 26. It is generally agreed that, whereas a flue should be as straight as possible for most of its height, it should have at least one bend in order to reduce down-draught and the admission of rain ; hence the reason for not continuing the upper flue in a straight line to the chimney pot ; if this flue was straight throughout, it would undoubtedly produce a smoky chimney because of its short length. Any bends must be gradual and should not be less than 45° to the horizontal. The brickwork enclosing flues shall be at least 4-in. thickness (see J, W and X) ; if the angle of an oblique flue is unavoidably less than 45°, this thickness must be increased to a minimum of 8½-in. on its upper side ; the minimum thickness of the back of a flue in a party wall (not back-to-back with another flue) must be 8½-in. up to its intersection with the roof. The minimum thickness of chimney breast walls is 4-in. (see C). The inside of a flue must be rendered with mortar to prevent the escape of flame and smoke through any cracks or open joints ; this is known as *pargeting* or *parging*, and should be at least ½-in. thick.

A good mixture for parging is composed of 1 part lime to 3 parts sand, together with ox hair (1-lb. of hair to 3 cub. ft. of mortar) well raked in ; another recommended mixture consists of 1 part cement, 3 parts lime and 10 parts sand ; an old specification, still adopted in country districts and which produces a very adhesive non-cracking coat, is 1 part lime, 2 parts sand and 1 part cow dung.

This parging is applied in course of construction, and in order to keep the flue clear of mortar droppings, pieces of brick, etc., it is advisable for it to be *cored*. A " core " is a sack, stuffed with shavings, with a rope attached ; it is placed within the flue at its commencement, drawn up in stages as the work proceeds and any droppings removed. This precaution is often omitted and hence the somewhat frequent cause of smoky chimneys, the accumulation of mortar, brick bats, etc., at the bottom of a bend being such that the passage of smoke is impeded and sometimes completely stopped. An additional precaution to ensure a clear flue is to leave an opening in the face of the chimney breast at the bottom of a bend which is unavoidably sharp, and this is made good after any accumulation has been removed.

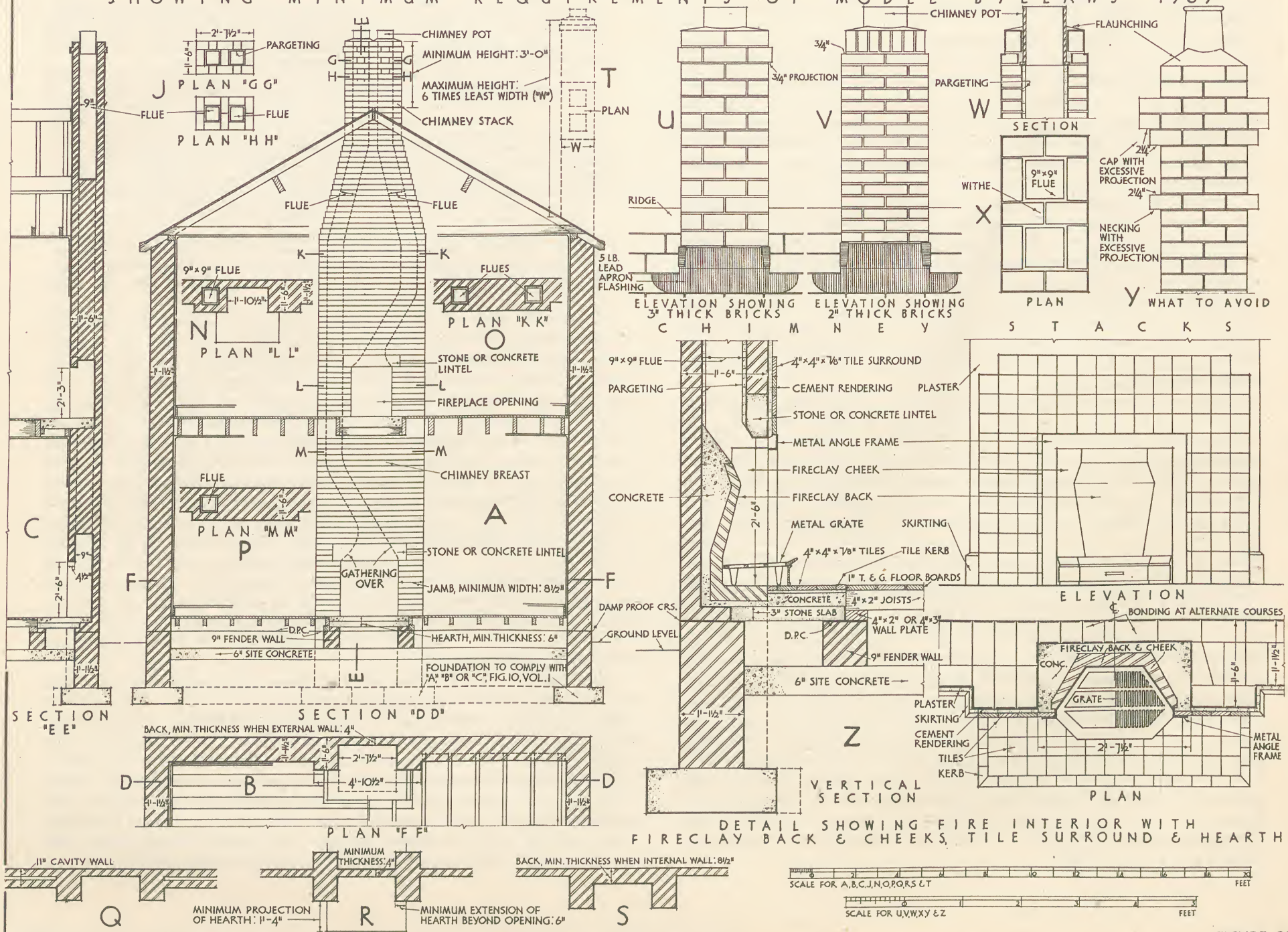
Flues in chimneys constructed of stone (which is occasionally used where stone is readily available) are lined with either cylindrical or rectangular fireclay *tubes* which are ½-in. thick, 8-in. internal diameter (or square) and 2-ft. long. These tubes are butt jointed and solidly backed with mortar ; any bends are blocked out with mortar to avoid cutting and mitring the edges of the tubes. Such linings are now rarely used, as most chimneys are built of brickwork.

CHIMNEY STACKS.—A chimney breast which is to penetrate the ridge of a roof is gradually reduced in width above the ceiling until that of the chimney stack is obtained, which should occur just below the penetration (see A). The minimum height of the stack is 3-ft. above the ridge, as shown. If the stack does not pass through at the ridge but penetrates one slope only, this 3-ft. height is measured from the highest point of intersection, such as at the back gutter. For reasons of stability, the maximum height of a stack is six times its least width (unless otherwise secured) measured from the highest point of intersection (see T). The minimum thickness of the walls of a stack is 4-in. If the stack only accommodates one flue, the appearance is considerably improved if this thickness is increased to 9-in. The 4½-in. thick *withes* (or divisions) should be well bonded into the external walls. Plans showing typical bonding are shown at J and X. Chimney stacks should be built in waterproofed cement mortar from 12-in. below the lowest point of intersection of the roof ; the parging of the flue above this level should also be of this material. Rain is thus prevented from soaking down the walls, and, provided the joints are well filled with mortar, cold air is excluded which would otherwise cause chimneys to smoke as the rising warm air is cooled.

It is usual to terminate a flue with a fireclay pot, although this is not always necessary and its omission is sometimes preferred. Chimney pots are of various shapes and sizes, a simple type being cylindrical, of 8-in. (or 9-in.) internal diameter, ½ to ¾-in. thick, and with a flange at the base ; its height varies, 12-in. being common ; it is often tapered to about 7½-in. (internal) at the top to give a restricted outlet which is considered to have the effect of increasing the velocity of the ascending current. The pot should be supported on the brickwork (see W) and securely built in cement mortar between two or three courses of brickwork (or a stone cap or several courses of tiles) ; the top of the stack is *flaunched*, *i.e.*, covered with cement mortar, which is weathered to throw off the water.

FIREPLACE ETC CONSTRUCTION

SHOWING MINIMUM REQUIREMENTS OF MODEL BYELAWS 1939



ALTERNATIVE PLANS TO "B" SHOWING EXTERNAL WALL AT "Q", BACK-TO-BACK OPENINGS AT "R" & INTERNAL WALL AT "S"

FIGURE 25

Many buildings are marred by unsightly chimney stacks which penetrate the roofs at random. As a rule, stacks should be of simple design. A frequent mistake is to complete stacks with *cappings* of oversailing courses with excessive projections. The coarse finish which these give is shown at Y, where the capping and necking courses are given a 2¼-in. projection. Ugly chimney pots are common. Tall chimney pots are unnecessary, unless the flues are short or have been improperly constructed, or high trees and buildings are in such close proximity as to produce down-draughts. An unobtrusive but effective finish may be obtained if the chimney pots (or short lengths of drain pipes) are caused to project not more than 1-in. above the flaunching ; this is usually sufficient to prevent eddies of wind which may be created if the top surfaces of the stacks were flat.

Two simple designs are shown at U and V. The former stack is constructed of standard 3-in. bricks with an oversailing course having a small projection. The stack at V is built of 2-in. bricks, and is finished with a brick-on-edge course set back ¾-in. ; part section and the plan are shown at W and X. The appearance of a chimney stack is much improved if thin bricks are employed. The leadwork conforms with the details shown in Fig. 73, Vol. I.

HEARTHS.—These must be of incombustible materials and securely supported. The *back hearth* (that within the fireplace recess) is bedded on the walling of the breast (see C) or as shown at Z. The *front hearth* must have a minimum thickness of 6-in. (see A), a minimum extension beyond the opening at each end of 6-in. (see R), and a minimum projection from the breast of 1-ft. 4-in., as shown at R. The support and trimming of front hearths are illustrated in Figs. 32, 33 and 34, Vol. I ; the section at Z shows an alternative treatment of a ground floor hearth. The bye-laws state that no woodwork shall be built in under a fireplace *opening* within 10-in. of the upper surface of the back hearth.

Additional bye-laws designed to prevent fires include the following :—

The external face of a chimney forming part of an *internal* wall less than 8½-in. thick shall be rendered with cement or lime mortar (not less than ½-in. thick) up to the roof. Similar rendering must be applied if woodwork (as at floors and roofs) is placed within 2-in. of walls of flues and fireplace openings which are less than 8½-in. thick.

Woodwork (such as joists) shall not be built in a wall or chimney breast within 9-in. of a flue or fireplace opening.

Wood plugs shall not be driven into a wall or chimney breast within 6-in. of a flue or fireplace opening.

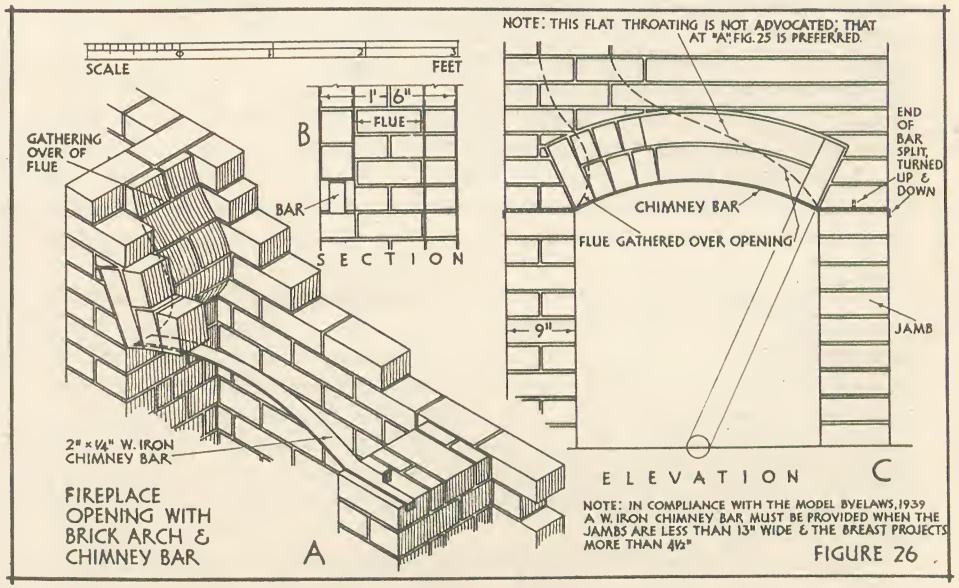
Fires have been caused by plugs (used for fixing skirtings, picture rails, grounds for panelling, etc.) which have been driven through joints and actually penetrated flues. It is therefore important that joiners should know of the position of flues when fixing wood members round chimney breasts.

Metal fastenings, such as nails, screws and holdfasts, shall not be placed within 2-in. of a flue or fireplace opening.

Holes in a chimney for the insertion of ventilating outlets or pipes from a heating stove shall not be made within 9-in. of any timber.

FIRE INTERIORS.[1]—Details of a simple fire interior, suitable for the ground floor opening at A, are shown at Z. This consists of a fireclay block with base, inclined back and splayed sides or *cheeks*, a metal (cast iron) grate, metal (stainless steel, etc.) angle frame, and a surround of 4-in. square glazed tiles. The fireclay block is bedded on mortar and backed solidly with concrete or brick in cement. The upper surface of this backing should be sloped as shown to prevent soot from accumulating ; if left square, as is sometimes advocated, the large accumulation of soot will be blown into the room in the event of down-draughts. The tiles are bedded on the cement rendering. The tiles and simple kerb forming the front hearth are bedded in cement mortar. The back of the block is inclined forward and its sides are splayed in order to throw the maximum heat into the room.

[1] These are more fully described in Vol. IV.


NOTE: THIS FLAT THROATING IS NOT ADVOCATED; THAT AT "A", FIG. 25 IS PREFERRED.
SCALE
FEET
1'-6"
FLUE
B
GATHERING OVER OF FLUE
BAR
SECTION
END OF BAR SPLIT, TURNED UP & DOWN
CHIMNEY BAR
FLUE GATHERED OVER OPENING
JAMB
9"
2" × ¼" W. IRON CHIMNEY BAR
FIREPLACE OPENING WITH BRICK ARCH & CHIMNEY BAR
A
ELEVATION
C
NOTE: IN COMPLIANCE WITH THE MODEL BYELAWS, 1939 A W. IRON CHIMNEY BAR MUST BE PROVIDED WHEN THE JAMBS ARE LESS THAN 13" WIDE & THE BREAST PROJECTS MORE THAN 4½"
FIGURE 26

SETTING OUT

A brief description of the construction of walls is given on p. 31, Vol. I.

Prior to the commencement of building operations the site must be surveyed and any differences in level of the surface obtained by means of an instrument called a *dumpy level*. The trenches to receive the foundations must be first *set out* or *pegged out* before their excavation is begun. If the site is sloping, and before the trenches are set out, it may be necessary to level the surface by excavating the higher parts and removing the soil to the lower portions as required. *Boning rods*, as described on p. 75, are used for levelling.

The first line to be set out is generally that of the main frontage of the building. As a linen tape stretches and is unreliable, a steel tape is used to

measure off its length and fix its relative position. A wood peg or stake is driven in at each end, the centre of the pegs indicating the position of the quoins. The lines of all other walls are measured off from this front wall line.

The plans of most buildings must be approved by the local authority before building operations are commenced. A plan submitted for approval will include the *block plan* of the building on which is shown the site, drainage, relative position to adjacent streets, etc. If the site adjoins existing buildings or a highway, it is very important that the *frontage line* shall be accurately set out in order that it shall not encroach beyond the *building line*, the position of which is obtainable on application to the local authority.

If a building is rectangular, right angles are set off from the main line by using the " 3 : 4 : 5 " method, *i.e.*, a distance of 40-ft. is measured along the line from one end and a *pin* (or *arrow*, made of stout wire, about 9-in. long, ring-shaped at one end and pointed at the other) is inserted ; a tape is held at each end of this length, the 30-ft. division on one of the tapes is held at the 50-ft. division on the other, both tapes are stretched taut and a pin is inserted at the intersection. The 30-ft. line thus set off is at right angles to the main line, as, in a right-angled triangle, the sum of the squares on the two sides containing the angle equals the square on the hypotenuse, *i.e.*, $40^2 + 30^2 = 50^2$. The large wood square shown at R, Fig. 27, is also used for setting out and checking right angles.

It is necessary to fix the height of one of the floors of the building, usually the ground floor level, to which all other heights are related. If possible, this should be a permanent level, such as the top of a plinth or step of a conveniently situated existing building ; otherwise a peg is driven in a position on the site, preferably opposite a door opening where it is not likely to be disturbed, until its top coincides with the required level as determined by a dumpy level or other means. The height that the top of this peg is above the ground should be noted and booked in case the peg is surreptitiously or accidentally lowered and a subsequent check is required.

PROFILES are used to ensure the accurate setting out and construction of the walls. These are temporary guides, consisting of boards nailed to wood pegs which are driven into the ground. Details of profiles are shown in Fig. 27. A key plan of a building is shown by broken lines at A, and the various profiles are indicated at the corners and opposite to division walls. Enlargements of these profiles are shown in the plan G and the sketches B and C. A corner profile is made of three pegs, well driven in, to which two boards are nailed. One profile is placed at each corner (see A and G), with the boards parallel to and at 2 to 3-ft. from the outer trench lines. The top of the corner peg at least of each profile is often the level of the ground floor. A steel tape should be used when setting out these profiles, and the measurements checked. A useful check is obtained by taking diagonal measurements between opposite corners, and if the building is rectangular, these should, of course, be equal. Permanent dimensions are marked on each board indicating the width of the concrete bed, brick footings (assuming that these are to be provided) and the thickness of the wall (see B and G). Saw-cuts, about $\frac{1}{2}$-in. deep, are made down these marks in the upper edge of each board to receive the ends of the bricklayer's line. Each profile used for division walls consists of two pegs and a board, and the latter is similarly marked and cut (see C and G). The centre lines of the walls are sometimes marked.

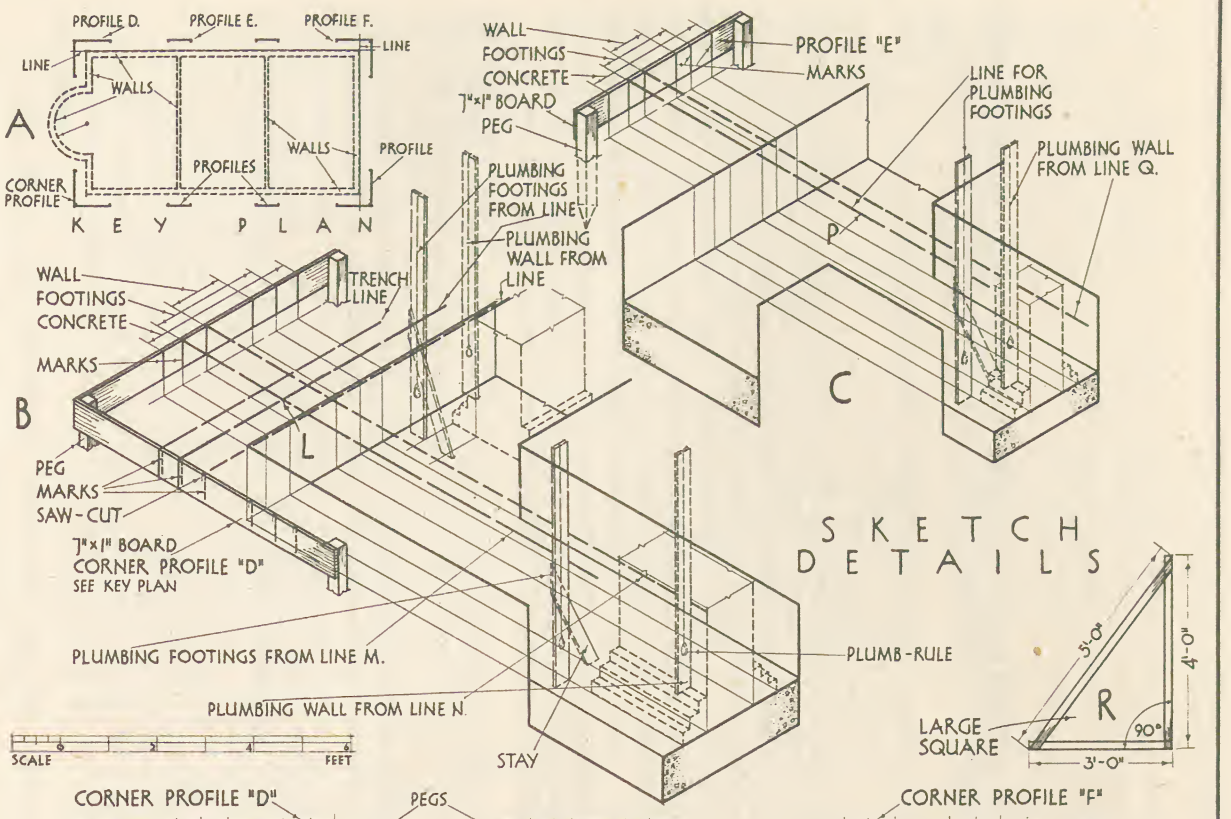
The position and correct alignment of the trenches, footings and walls are obtained by plumbing down from lines which are stretched in turn between opposite profiles. Thus, assuming that the trenches have been lined out and excavated, and the concrete [1] has been placed in position, the bottom course of footings would be aligned in the following manner : One end of a line (see M and P at B and C) is passed down the saw-cut at the top of the appropriate mark and wrapped round the board, and after the line has been stretched taut the opposite end is fixed in a similar manner. The plumb-rule, sometimes stayed as shown (the stay being nailed to the rule), is held by one hand against the line near one end of the trench and, when vertical, a mark is made by the point of the trowel in a little mortar trowelled on the concrete bed. A brick is laid temporarily on this mortar with the outer face in line with the mark ; the plumbing of this face is checked. Another brick is laid in a similar manner at the other end. A bricklayer's line, with pins, is fixed between and level with the top of these bricks. The bottom course of footings is then built, commencing at the corners, the position of each of which is found by plumbing down at the intersection of the two lines (see L at B). Similarly, the wall is set off correctly by plumbing down from lines N and Q shown at B and C.

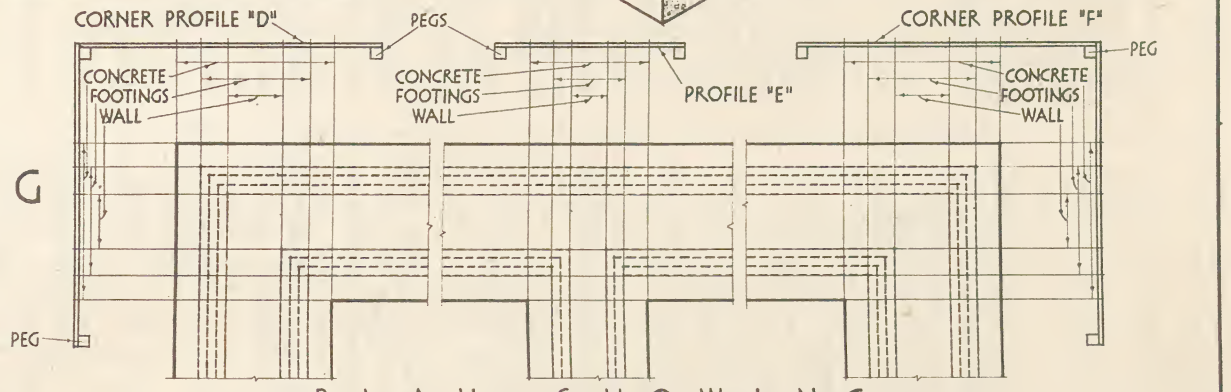
Sometimes two profiles, like E shown at G, are used for the two walls forming a quoin instead of a corner profile. Profiles for division walls are often dispensed with, the right-angled intersections being then checked by the use of the large square R. Corner profiles for setting out squint quoins (see Fig. 11) have their boards parallel to the sides of the walls, and a division wall which forms a squint junction (see Fig. 10) is set out by placing the two profiles, one at each end, at right angles to its length.

Whilst profiles assist in the accurate setting out and construction of walls, their use is by no means general. In the absence of profiles the lines of the trenches are pegged out, two pegs being driven in at each end of a trench at a distance between their outer faces equal to its width ; the line is stretched in alignment with these outer faces ; these pegs, like the profiles are placed some 2-ft. outside the lines of trenches.

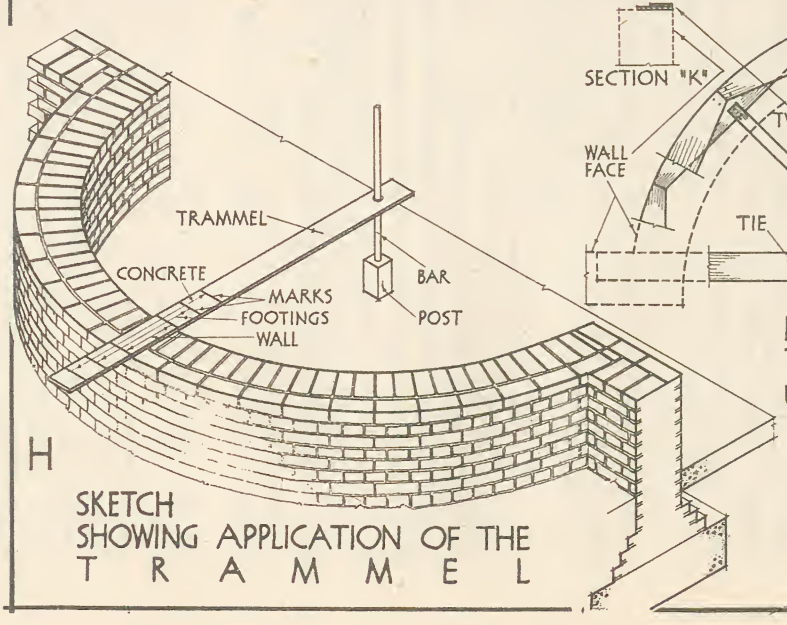
[1] *Levelling Concrete Bed.*—A peg is driven in the bottom and at each corner of the trenches until the top of each is at the required depth below the floor level : this depth is obtained by means of a 2-foot rule and the use of a spirit level and short straight edge applied on the corner peg of the nearest profile. If this depth is in accordance with the gauge of the brickwork decided upon, the floor level will course with the bed joint of the brickwork. Intermediate pegs are then driven in the bottom of the trenches at convenient intervals until their tops are at the same level as the corner pegs. This is assured if three boning rods (see p. 75) of the same height (about 4-ft.) are used, one on each of a pair of corner pegs and the third on the intermediate pegs in turn, and " sighting through " from one end. The concrete is carefully deposited and brought approximately to the level of the peg tops. A horizontal surface is obtained by using a striking-off board (see p. 60) on each pair of adjacent pegs in turn. These wood pegs must be removed before the concrete has set, and the holes filled with concrete. If allowed to remain the pegs may rot and be responsible for the onset of dry rot in floor, etc., timbers (see pp. 14-16, Vol. III).

SETTING OUT

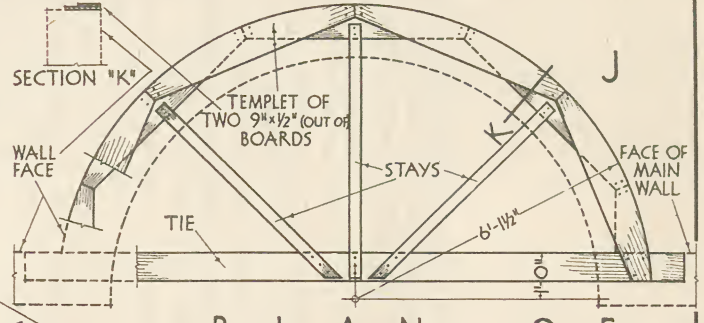




PLAN SHOWING SETTING OUT OF WALLS



SKETCH SHOWING APPLICATION OF THE TRAMMEL



PLAN OF TEMPLET USED INSTEAD OF THE TRAMMEL

SEE FIG. 15.

FIGURE 27

After the trenches have been excavated to the required depth and the concrete beds formed, the alignment of each wall is maintained by placing the quoin bricks in correct position, as described on p. 68, and stretching a line between.

CIRCULAR WORK.—This may be set out by using either (*a*) a *trammel* or (*b*) a *templet*.

(a) *Trammel Method.*—The application of a trammel for the bay window indicated at A is shown at H, Fig. 27. The bonding of this wall is shown in Fig. 15. A trammel is a ½-in. thick board, not more than 6-in. wide, and holed at one end. A ¾-in. diameter metal bar is set up vertically in a slab of concrete at the centre of the circle; the length of the bar must be sufficient to reach to the top course of the proposed wall, and must be vertical, as tested by a plumb-rule. Alternatively, the rod may be tightly fitted into a wood peg or post which has been driven into the ground at the centre. The trammel is threaded over and passed down the bar, and the width of the concrete (and footings) and the thickness of the wall are accurately marked on its upper face. The setting out and construction of the semicircular (or segmental) wall are aided by the trammel as it is caused to rotate, and by plumbing. As the brickwork proceeds above the ground level, the trammel, which must be horizontal, is supported at its holed end by a piece of cord which is fastened under it to the bar, the cord being raised as each course is completed.

(b) *Templet Method.*—This is often preferred to the trammel on account of its convenience and the accurate check which it affords. A templet consists of two wide thin pieces of board, everlapped and nailed to each other, as shown at J. The outer edge is sawn and carefully planed to the required curve. A wood tie connects and projects beyond the two ends, and the outer edge of this tie must coincide with the external face of the main wall. Three wood struts or stays are fixed as shown; these make the templet rigid and convenient for handling. The templet is placed as required on top of each course during and after its construction, any bricks not conforming to the curve being tapped in or out until their outer faces correspond to the curve. Plumbing provides a further check on the work. It is most important that the outer edge of the tie is in true alignment with the main wall face each time the templet is used.

GENERAL.—In conclusion, it is most important that the following requirements be observed if best results are to be obtained when setting out facing work :—

1. *The normal face appearance of the selected bond must be maintained over and under openings.* Hence the average length of the bricks should be carefully noted and, as stated on p. 13, Vol. I, the width of each opening should be a multiple of 1 brick for English bond, and for Flemish bond the width should be a multiple of 1½ bricks after 18-in. wide; the combined thickness of the vertical or cross joints must, of course, be allowed for. Thus, for English, English garden wall, and stretcher bonds, the size of an opening may be 9-in., 1-ft. 6-in., 2-ft. 3-in., 3-ft., 3-ft. 9-in., etc., plus the combined thickness of the vertical joints; for Flemish and Flemish garden wall bonds, the width may be 1-ft. 6-in., 2-ft. 7½-in., 3-ft. 9-in., 4-ft. 10½-in., 6-ft., etc., together with the cross joints.

If these dimensions are departed from when the above bonds are adopted, broken bond is inevitable. An example of broken English bond above an opening is shown at N, Fig. 19; note the stretching course immediately over the crown. Unsatisfactory features of broken bond are the non-maintenance of the perpends and unbalanced treatment at the jambs of openings (such as a stretcher at one side and a header or bat in the same course at the other).

2. *The length of walling between openings and the width of external attached piers should be in accord with the average length of the facing bricks.* Thus, for example, broken bond will be avoided if these lengths and widths are multiples of whole bricks (plus the total thickness of the vertical joints) and the bond is either stretcher, English or English garden wall.

It is usual to mark the above position of door and window openings, etc., on the course of common brickwork (generally 3-in, below the ground level) and when constructing the faced work to make certain that the appropriate perpends are vertically under the reveals concerned.

3. *Split courses above arches and lintels* (see p. 21, Vol. I) *and below sills must be avoided.* Therefore the average thickness of the bricks and the bed joints must be taken into account when deciding upon the height of most openings and the construction must conform to the gauge rod (see p. 31, Vol. I) on which the courses are indicated. It is good practice to arrange that a stretcher is the first (reveal) brick in each of the courses immediately above the sill and below the arch. To attain this, it is necessary that the number of courses between the ground level and the sill course shall be carefully ascertained and the bonding arranged accordingly.

Accurately set out brickwork is no more expensive than that which is constructed in a haphazard fashion, and whilst the above preliminaries to actual construction will involve some thought and the expenditure of a little time, the results obtained are well worth while.

CHAPTER TWO

DRAINAGE

Syllabus.—Characteristics and brief description of the manufacture of drain pipes, including bends, junctions, channels and taper pipes, gullies and interceptors. Setting out and construction of drains. Drainage systems for small buildings ; inspection, interception and ventilation.

SEWAGE DISPOSAL.—In addition to rain water, the waste and refuse required to be disposed of from houses and other occupied buildings include (1) liquid wastes from sinks, lavatory basins and baths, (2) excrement and (3) ashes and household refuse.

Where there is an inadequate water supply, such as in certain rural districts, the rain water is usually collected in galvanized iron tanks and used for household purposes, and fixed receptacles known as *privy middens*, *earth closets* or *ash closets* are provided for excrement, ashes and other refuse. Another objectionable but less insanitary form of accommodation existing in certain districts, including a number of large townships, consists of *pail closets* or *tub closets* in which movable receptacles for fæcal matter are provided, ashes being received in small dust bins. This is known as the *dry* or *conservancy system* of sanitation.

The best system, now in general use, is known as the *water-carriage system*. This provides for the admission to and removal by pipes of the liquid wastes from sinks, baths, etc., and excreta. These combined wastes and excreta are called *sewage*.

A complete sewerage or drainage system consists of a network of pipes conveying sewage, the smaller pipes being connected to larger ones and these ultimately combining to form what is called a *main outfall sewer*.

The method of disposal of sewage depends a good deal upon the location of the district. Thus, that from a coast town is simply disposed of by continuing the outfall sewer some distance on the sea bed and allowing the sewage to discharge into the sea during the ebb-tides. If a tidal river is conveniently accessible, the sewage may be discharged into it after it has been passed through a settling tank or received similar preliminary treatment. Otherwise the outfall sewer is continued to the *sewage disposal works*, where the sewage is treated and rendered innocuous. One form of treatment, known as the *activated sludge system*, consists of passing the sewage through a screen and a settling tank prior to admitting it to a large rectangular tank where it is agitated by compressed air admitted at the floor level. In another method the sewage after being screened and settled is sprayed over a *percolating filter* consisting of a 6-ft. deep bed of gravel or similar material. Another method, now being gradually superseded by the activated sludge system, consists of the admission of sewage to one or more *contact beds* of gravel or broken bricks, etc., where it is allowed to remain for several hours. If only a comparatively small system, the sewage, after preliminary screening and settling to eliminate as much as possible of the solid matter (called *sludge*), may be distributed over land. After being treated by one of these methods, the purified liquid or *effluent* is discharged into the nearest watercourse. In each of these systems the sewage is rendered harmless by the action of bacteria and oxygen.

In the absence of a conveniently situated public sewer (see next column), and where no nuisance is likely to occur, the sewage from a country house may be conveyed to a *septic tank* (similar to the inspection chamber shown in Fig. 31, but with the outlet at the same level as the inlet and several feet above the floor) or " cesspool " and then allowed to percolate through the soil (provided it is gravel or is otherwise suitable) or passed over a small filter bed of clinker, etc.

In some districts the rain water is kept separate from the sewage, one set of pipes taking the former and another the sewage ; this is known as the *separate system*. Most local authorities, however, adopt the *combined* or *single-sewer system*, in which one set of pipes takes both sewage and rain water.

The channels or pipes which convey sewage are called *drains* or *sewers*. The essential difference between a drain and a sewer is concerned with ownership. A sewer belongs to a local authority, who is therefore responsible for its maintenance ; a drain is the property and responsibility of an individual. Briefly, according to the Public Health Act, 1875, a drain is a channel by which sewage is conveyed from a single house or premises within the same boundary ; if it serves more than one house, the channel is a sewer. Much litigation has resulted in determining whether pipes were drains or sewers, and whilst the above is a broad distinction, it may not apply in districts where local authorities have obtained special powers under private acts or have adopted provisions under the Public Health (Amendment) Acts.

DRAIN PIPES AND TRAPS

Drain pipes and traps are made of clay or shale and cast iron.[1] When made of the former they are known as *stoneware* or *fireclay* or *earthenware* pipes. These terms are often loosely applied. The clay from which stoneware pipes are made is found in this country in the south and midlands, and fireclays are obtainable in the north. Both produce drain pipes and traps of first quality. Generally, the term earthenware is applied to drain pipes and traps which are made from clays used chiefly for the manufacture of bricks, and the quality is variable. In the British Standards Specifications, Nos. 65 and 539—1937,[2] the term " ware "

[1] Cast iron drainage is detailed in Vol. IV.

[2] Extracts from these are made by courtesy of the British Standards Institution, 28 Victoria Street, London, S.W.1.

is applied to clay pipes and traps. These sanitary goods are *salt-glazed* (see p. 74) to render them impervious.

Drain pipes are illustrated in Fig. 28, and include straights, bends, junctions, tapers and channels.

STRAIGHT PIPES (see A, B and C, Fig. 28).—The cylindrical *barrel* has a *flange* or *socket* at one end, and the opposite end is called the *spigot* or *faucet*. The interior of the flanges and the exterior of the spigots are grooved to a minimum depth of $\frac{1}{16}$-in. to afford a key for the jointing material. The *internal* diameter varies from 3 to 36-in. The Model Bye-laws stipulate that the diameter of drains conveying sewage must not be less than 4-in.; this size is sufficient for most house drainage systems of average size, and very rarely are pipes exceeding 6-in. diameter required for this purpose. The larger pipes are used for public sewers and 2 and 3-in. pipes are utilized for subsoil or agricultural drainage. The length of the barrel, *exclusive* of the flange, varies from 2 to 3-ft., that of 4 and 6-in. pipes being 2-ft. The *minimum* thickness of pipes, size of flanges, etc., are shown in the table at C.

RADIUS BENDS (see H and J).—These are required at horizontal and vertical changes of direction of straight lengths of drains. The standard radii of 4 and 6-in. pipes are shown. They are described in accordance with the number of bends required to make a complete circle, thus that at H is known as a quick or *quarter bend*, the 135° example at J is called an *eighth circle bend*, and the slow bend having a contained angle of $157\frac{1}{2}°$ (see J) is called a *sixteenth circle bend*. A bend required to change the direction of a drain on plan should be slow or "easy," and two eighth circle bends are preferable to a single quarter bend. Whilst the latter should never be used for this purpose (unless the drain conveys rain water only), they can be usefully applied at the foot of vertical soil and ventilation pipes (see p. 82), or at the bottom of short branch drains where they enter inspection chambers (see p. 80, or as shown at E, Fig. 32).

JUNCTIONS (see U and V).—Such are necessary at connections between drains. That at U is called a *single junction* and is specified according to the internal diameters of the connecting pipes, *i.e.*, 4-in. by 4-in., 6-in. by 4-in., 6-in. by 6-in., etc. The branch or *arm* of a junction should be obliquely inclined in the direction of the flow of the sewage. Right-angled or square junctions must never be used; a branch pipe which is unavoidably at right angles to a main drain should be connected by means of an oblique junction and a slow bend. A *double junction* is shown at V; they are not advocated, an inspection chamber (see p. 80) being preferred; the arms should be the maximum distance from each other, and a better arrangement is to use two adjacent single junctions.

TAPER PIPES (see K).—These are necessary when the size of a drain has to be increased on account of one or more additional branches which may be connected to it lower down its length. That shown is of the *level invert* or *straight invert* type, the invert being the lower internal surface. Another type has the socket concentric with the spigot, and thus there is a slight fall in the invert from the socket to the spigot. Tapers are specified according to the size of the adjacent pipes, *i.e.*, 6-in. by 4-in., 9-in. by 6-in., etc. Very occasionally, as for alteration work, a taper pipe is required having the socket at the larger end. A standard 6-in. by 4-in. *taper bend* is shown at W.

CHANNEL PIPES, required at inspection and disconnecting chambers, are described on p. 80 and illustrated in Figs. 30 and 31. A standard channel bend is shown at X, Fig. 28.

TRAPS.—These are made of salt-glazed ware and cast iron, and include *gully traps* and *intercepting traps*.

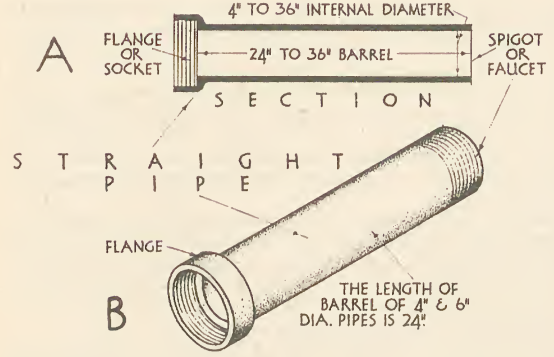
Gully Traps or *Gullies* (see Q, R, S and T, Fig. 28).—The Model Bye-laws require that waste pipes from lavatory basins, baths and sinks shall be disconnected from a drain by a "trapped gully with a suitable grating above the level of the water in the trap." Gullies are also placed at sides of roads and paths, and in yards and other paved surfaces (see garage concrete wash at A, Fig. 31) for the purpose of receiving rain water and that used for cleaning purposes.

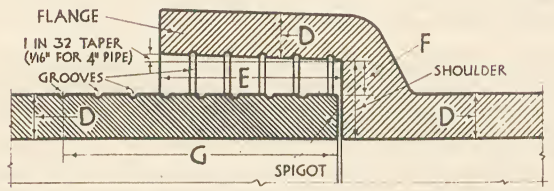
The object of the trap is to prevent gases escaping from the drain and polluting the atmosphere. A gully takes the form of a bent channel (see Q) with the inner fold projecting into the retained liquid and $2\frac{1}{2}$-in. below the outlet to form the *seal*. The internal surface is curved throughout, varying from 6-in. at the inlet and 4-in. at the outlet. It is of the *self-cleansing* type, as it permits of the free passage of waste liquids, and the absence of angles and corners prevents any accumulation of small pieces of organic, etc., matter. The flat base enables the gully to be bedded correctly, and as shown at C, Fig. 32, it is set on 6-in. of concrete. The top length of the drain is connected as shown by broken lines; if required, additional cover and protection is afforded to the upper end of the drain by using a gully having a curved outlet such as that shown at A, B and C, Fig. 32. The inlet is provided with a flange to receive the cylindrical rim of the square *dish* (see Q and S), the joint between the two being of cement mortar. As shown, the dish is slightly rebated for the cast iron *grid* or *grating* (see also R). Standard gullies are shown at A and B, Fig. 32 (see p. 84).

There is a difference of opinion as to whether a waste pipe should discharge over or under the grating. Most authorities insist upon the former, and the dish is therefore useful in preventing waste liquid from splashing and fouling the adjacent ground or pavement. The undercut type of dish, indicated by broken lines at Q, is more effective in preventing the discharge from an upper floor bath waste pipe from overflowing (see p. 84). This type of gully with circular top and separate dish is much preferred to the *square grid gully* which has a square rebated top to receive the grating direct. As the latter has no separate dish, it is often impossible to fix it square with the wall of a building unless a bend (on plan) is provided at the beginning of the branch drain; an additional undesirable feature of the square grid gully is the fouling of the adjacent surfaces which results from discharges from waste pipes, unless somewhat unsightly brick-on-edge or stone kerbs are provided at the edges.

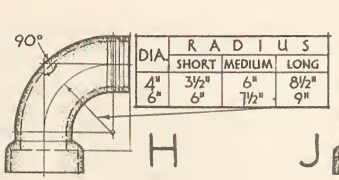
All rain water pipes must discharge over gullies and shall not be connected direct to a drain forming part of a combined drainage system (see p. 71), other-

DRAIN PIPES & TRAPS





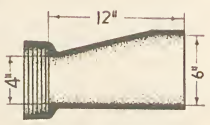
DIAMETER OF PIPE	"D"	"E"	"F"	"G"
4"	½"	2"	⅜"	3"
6"	⅝"	2¼"	7/16"	3⅜"
9"	¾"	2½"	½"	3¾"
12"	1"	2¾"	⅝"	4⅛"

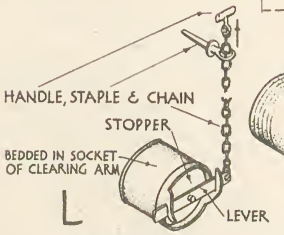


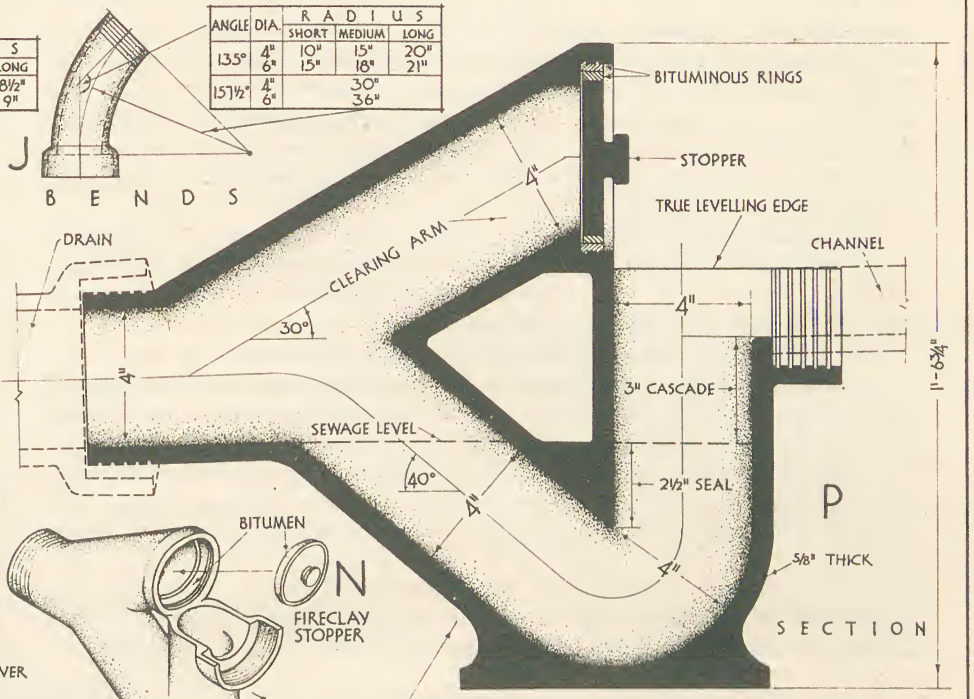
DIA.	RADIUS SHORT	RADIUS MEDIUM	RADIUS LONG
4"	3½"	6"	8½"
6"	6"	7½"	9"

RADIUS BENDS

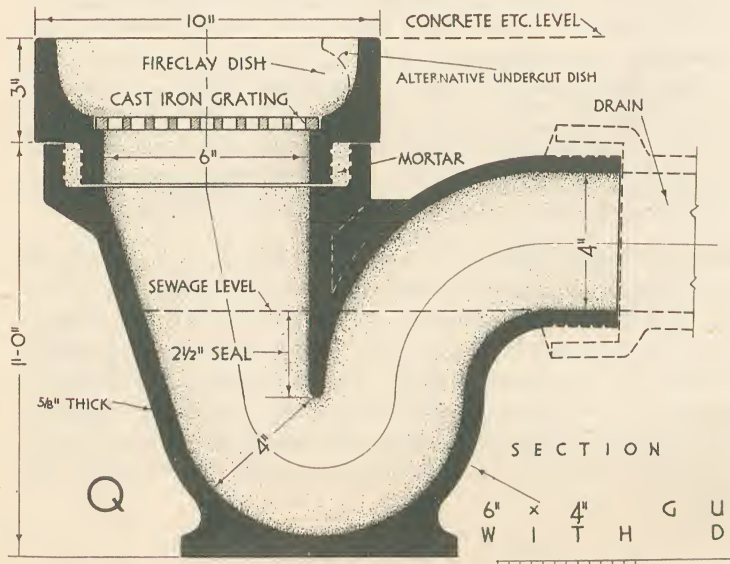
ANGLE	DIA.	RADIUS SHORT	RADIUS MEDIUM	RADIUS LONG
135°	4"	10"	15"	20"
	6"	15"	18"	21"
157½°	4"	30"		
	6"	36"		

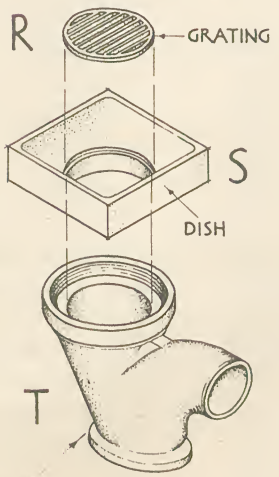


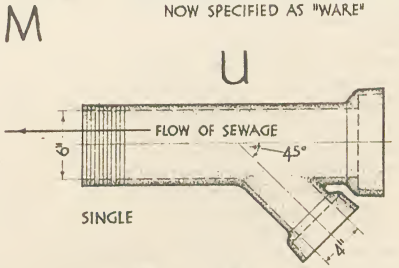


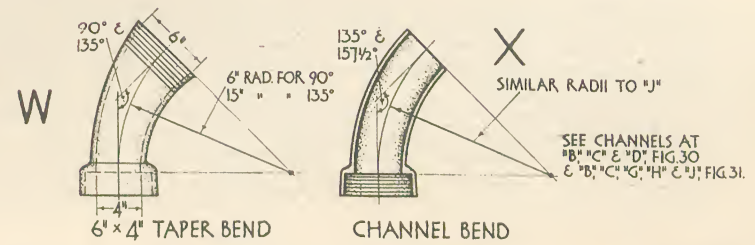


N.B. THESE PIPES & FITTINGS ARE OF SALT-GLAZED STONEWARE OR FIRECLAY NOW SPECIFIED AS "WARE"









SCALE FOR A, B, H, J, K, M, N, R, S, T, U, V, W & X — FEET

SCALE FOR P & Q — INCHES

FIGURE 28

wise gases from the drain will ascend and gain access into the building at the eaves. Some prefer the fall pipes to be discharged below the gratings of gullies for the reason that overflowing does not result if the former are choked with leaves, etc.; many authorities will not permit of this practice and insist upon the pipes discharging *over* gullies. As traps may become unsealed by evaporation during hot weather, it is advisable that water be poured down them occasionally during such prolonged periods.

All gullies must be fixed outside a house. In order to comply with this requirement in connection with a basement, it may be necessary to construct a small area (at least 2-ft. 6-in. wide for access) adjacent to an external wall, in the concrete floor of which the gully is fixed.

Applications of gullies are illustrated in Figs. 30, 31 and 32.

Intercepting Traps or Disconnecting Traps or Interceptors.—One of several types of this ware trap is shown at M and P, Fig. 28, and a similar trap is shown at B, Fig. 30. The seal increases from $2\frac{1}{2}$-in. for a 4-in. interceptor to 3-in. for 6-in. and 9-in. traps. The trap is fixed in an intercepting chamber (see Fig. 30), and its object is to intercept the sewer gases from the drainage system. Its adoption is becoming less frequent, and its merits and demerits are discussed on p. 82.

Manufacture of Drain Pipes and Traps.—The processes vary according to the class of clay and the plant available, but, as in brick manufacture, they are divided into the preparation of the clay, moulding, drying and burning.

The clay is finely ground and screened as described on pp. 2 and 3. Grog (or powdered burnt clay—see p. 3—or crushed burnt and damaged pipes) is added to the clay to reduce the shrinkage, some clays requiring 25 per cent. of this material.

Straight Pipes are moulded by machinery, which is of both the vertical and horizontal type. The former consists of a long fixed vertical metal outer cylinder having its lower end enlarged and shaped to the reverse of the exterior of a pipe socket, an inner fixed core with an annular space between it and the cylinder, and a disc or socket head (at the bottom of the core within the enlarged cylinder base) attached to a table which can be raised and lowered. The diameters of the cylinder, core and socket head are equal to the size of the pipe (see C, Fig. 28), plus shrinkage allowance.

After the base of the outer cylinder has been clamped to the table, the prepared clay of required stiffness is forced down the annular space by means of a steam ram until it has been sufficiently consolidated. It is thus the shape of a pipe, having a socket and an elongated barrel. The clamp is released, the table with socket head is lowered, and, assisted by the downward pressure of the ram, the hollow cylindrical shaft of clay is extruded and cut to the required length by means of a wire.

The pipe is removed from the socket head (which is then sprayed with oil before the table is raised ready for moulding the next pipe) and placed, with its socket uppermost, over a vertical core or mandrel fixed to a revolving table. The socket is trimmed and the grooves are formed either by a machine which is lowered into the socket, or by a comb held in place by hand, as the pipe revolves. It is then placed over a horizontal core where it is cut to correct length and the spigot grooved, the latter operation being performed by a small pivoted arm which is impressed into the clay as the core rotates.

After moulding, the pipes are wheeled and placed vertically on the drying floor and gradually dried in a temperature of 80° F. for one or two days.

They are then taken to the kiln, which is generally of the circular down-draught type (see p. 6). The pipes are carefully stacked vertically upon their sockets, one above the other, to a height of from 8 to 12-ft. The heat is gradually applied until a maximum temperature of about 250° C. is reached; this is known as the vitrification stage. The pipes are now glazed, the operation being called *salting*, as common salt (chloride of sodium) is used for this purpose. The amount of salt added varies, but a shovelful of salt thrown through each firebox four times during the salting period is usual. The heat volatilizes the salt, and the sodium combines with the silica of the clay to form the characteristic brown glazed surface coating. The inside of the sockets and the outside of the spigots are unglazed (except the spigots of the top pipes) as these are covered in the stacks, and thus a better key for the jointing material is obtained. Burning may occupy from three or four days, and cooling, which must be carefully controlled, takes the same time.

Junctions are made from straight pipes moulded as described in the preceding column. Thus, a small socketed piece required for an arm of a junction is cut from a freshly moulded pipe, its end is shaped by hand (or by a special machine), the cut edge is covered with liquid clay and fitted on to a recently moulded pipe. On the following day the required hole in the latter pipe is cut at the joining of the arm, trimmed with a knife and smoothed over with the fingers.

Bends are formed either by a machine, to which various dies can be fitted, or by hand. If the latter, a straight pipe as it emerges from the machine, is bent to the approximate radius, and then fitted over a core of the correct shape and trued up by hand.

Channels.—Two half-round channels are obtained from a whole green pipe. The latter is placed in a plaster-of-Paris mould which is half-round in section and the length of a pipe, and it is divided longitudinally by a piece of wire drawn along the top edges of the mould. The cut edges are then trimmed.

A three-quarter channel bend, such as is shown at G, H and J, Fig. 31, consists of a half-round channel bend (obtained by dividing a green radius bend) together with a length cut by hand to the required shape. These are stuck together with liquid clay and the joint neatly trimmed off.

Traps are moulded by hand in moulds made of plaster of Paris. Two moulds are required per trap. Each mould is shaped with its internal surface the reverse of the exterior of the trap to be moulded. Thus, for a gully such as that at T, Fig. 28, the moulds would be shaped to the exterior shown in section Q. A clot of prepared clay is flattened to the required thickness, and this is taken by the moulder who works it into the mould to the desired shape. When the two pieces have been moulded in this manner, the two moulds are brought together and clamped by bands of hoop iron. When the clay has sufficiently set, the moulds are removed and the junction is neatly trimmed and smoothed off. Interceptors are hand-moulded in a similar manner.

Junctions, bends, channels, traps, etc., are dried, burnt and salt-glazed as above described.

Whilst most channels are salt-glazed, they are sometimes required to be *white glazed* or *enamelled*. Enamel consists of powdered flint, china clay, powdered zinc, etc., well mixed together and water added to form a slurry. Glaze is a somewhat similar mixture with the addition of whiting, felspar and soda. The channels must be thoroughly dry before the enamel is applied. In best work three or four coats of enamel are first brushed on the internal surface and edges of each channel, and this is followed by two coats of glaze. This film is fused when the channels are heated in the kiln and forms a hard, durable, impervious and white coloured surface.

Characteristics of Ware Pipes.—A sound pipe should be well glazed and burnt throughout, straight in the barrel (twisted or warped pipes cannot be properly jointed), truly cylindrical, smooth, and free from cracks and blisters. It should ring sound when struck with a hammer. Requirements of the British Standard Specification, No. 65—1937, include: (1) the variation in thickness of the barrels and sockets of 4 and 6-in. pipes shall not exceed $\frac{1}{16}$-in., (2) the deviation from straightness of a 2-ft. long barrel shall not exceed $\frac{3}{16}$-in., and (3) the deviation of the internal diameter of 4 and 6-in. pipes shall not exceed $\frac{1}{8}$ and $\frac{3}{16}$-in. respectively.

For first-class work, British Standard Tested Salt-glazed Ware Pipes should be used. Each pipe is subjected to an internal hydraulic test at the works and should withstand a pressure of 20-lb. per sq. in. without showing signs of injury or leakage. The specification also includes an absorption test.

SETTING OUT AND EXCAVATION OF DRAIN TRENCHES

A drain must be laid to an adequate inclination or gradient. This is expressed as a ratio between the total fall (or difference in level between the upper and lower ends of the drain) and the horizontal length of the drain. Thus, if the fall is 2-ft. and the horizontal length is 60-ft., the gradient is 1 in 30. A 4-in. drain should have a minimum fall of 1 in 40 and a 6-in. drain a minimum fall of 1 in 60, *i.e.*, the diameter in inches is multiplied by 10.

Before deciding upon the gradient to which a drain is to be laid, it is necessary to obtain the depth of the public sewer (or existing drain or cesspool) and the level of the ground. The depth of the sewer below the ground level at the proposed point of connection may be obtained by inspection on the site, such as at a convenient manhole or chamber (see p. 80), or from the surveyor to the local authority ; the level of the ground along the proposed line of the drain is determined by using a dumpy level and levelling staff or the straight edge and spirit level. The longitudinal section, such as is shown at E, Fig. 30, can then be plotted. Besides having an adequate fall, the drain should be laid to a uniform gradient up to the boundary of the site, or from chamber to chamber (see p. 80), after which the fall may be increased up to the connection. Thus, at E the drain has a uniform inclination of 1 in 32 up to the intercepting chamber M, from which point the gradient is increased. In this example it would be uneconomical to maintain a uniform gradient from the gully to the sewer because of the additional excavation which would be entailed.

Unless the drain is a short one the setting out of the trench is performed in the following manner : A wood peg is driven in on the proposed centre line of the drain at each point where it changes direction. The sides are pegged out, pegs being inserted at half of the width from each centre peg ; a cord is stretched taut and tied to one pair of side pegs, the side is marked with a pick or spade, and the opposite side is similarly marked after the line has been transferred to the corresponding pegs.

The correct level of the bottom of the trench is obtained and a uniform fall maintained by the use of two *sight rails* and a *boning rod*. A sight rail is a wood board, having straight edges, and about 1½-in. thick. It is fixed to a pair of 4-in. by 2 or 3-in. wood posts, having pointed ends, which are securely driven into the ground at one end and clear of the proposed trench ; each post is sometimes packed with earth, gravel, etc., within a 6 or 9-in. drain pipe placed vertically with its flange resting on the ground. The sight rail is nailed to the two posts at any convenient height and with its upper edge horizontal as tested by a spirit level. The second sight rail is fixed at the correct level in a similar manner at the opposite end of the trench ; the level of the top edge of this rail must be such that an imaginary line, called the *line of sight*, drawn from it to that of the other is parallel to the proposed gradient of the drain ; a dumpy level and levelling staff should be used to fix the height of this second sight rail to ensure that the difference in level between the two rails is that decided upon. An application of sight rails is illustrated at A, C and D, Fig. 29, where the inclination of the line of sight is 1 in 40 and is 7-ft. 6-in. above the bottom of the proposed trench. The required gradient of the trench bottom is maintained by use of the boning rod. This rod resembles an elongated tee-square having a wood blade with cross head attached (see A, B, C and D). The height of the rod must equal the vertical distance between the line of sight and the predetermined level of the trench bottom, *i.e.*, 7-ft. 6-in. in this example.

The excavation is proceeded with until the level of the bottom of the trench is reached as determined by " sighting through." Thus, the foreman standing immediately behind one of the sight rails looks towards the far sight rail so that he can just see the top edges of both rails, and the required depth is indicated when the top of the boning rod, resting upon the bottom of the excavation and held vertically by an assistant, coincides with the line of sight. This is repeated the rod being held at intervals along the trench. The boning rod W at D, Fig. 29, shows that the required level of the trench at that point has been reached and that additional excavation is necessary further up if, when sighting through as the rod is held in turn at positions U and V, its head appears above the line of sight as indicated. Excavation of the last one or two inches may be deferred until just prior to the laying of the drain, when the earth is trimmed off and the bottom rammed solid.

Timbering, as required, is provided as a temporary support to the sides of the trench (see Fig. 42, Vol. I, and Fig. 19, Vol. III).

JOINTS.—These must be airtight and watertight; none of the jointing material must remain within the bore of the pipes, and the invert must be in true alignment throughout. The jointing material used for ware pipes is (1) cement and (2) bitumen.

1. *Cement Joint* (see G, Fig. 29).—This is the joint most commonly employed. The composition of the mortar recommended is 2 parts cement, 1 part sand and 2 per cent. of waterproof compound (see p. 27) ; sometimes neat cement is used, but this has been known to crack the pipe sockets owing to the expansion of the cement (probably of indifferent quality) when setting ; another mixture, often used, consists of equal parts of cement and sand. In addition, it is customary to use a piece of *yarn* (also known as *hemp*, *gaskin*, *gasket*, *jute* and *rope*) at each joint.

The joint is formed in the following manner : The spigot of a pipe is placed within the socket of the last laid pipe and closely butted against the shoulder. A piece of yarn, after being dipped into a pail of cement grout to preserve it (unless it has been previously tarred) is wrapped two or three times round the spigot and well caulked against the shoulder by means of a blunt chisel, cement

mortar is packed in by hand to completely fill the annular space, and this is neatly finished by a fillet splayed by a trowel at an angle of about 60°. The object of the yarn is twofold, as it prevents the entrance of the cement to the inside of the drain and assists in centering the pipes to maintain a properly aligned invert.

Some jointers prefer to omit the preliminary packing of the joints with yarn. Accordingly, unless the mortar is of a stiff consistency, much of it will pass within the drain and a " dropped invert " will result as the pipes, because of their weight, will subside and squeeze out some of the material. Such a faulty joint is shown at H. If the projecting mortar is not removed, as explained in next column, paper and solids may accumulate to cause an obstruction in the drain ; lodgement may also be caused by the dropping of the spigot. The unsightly appearance produced by an excess of mortar and the absence of a fillet is also shown.

2. *Bituminous Joint.*—Of the many patent joints on the market that shown at J, K and L, Fig. 29, and known as the Hassell's Double-lined Joint, is one of the oldest and best. Each pipe has two solid bituminous rings moulded on the inside of the socket with a 1-in. space (for a 4-in. pipe) between, and two similar rings are cast on the spigot (see K). Two holes are provided in the socket (see L). The joint is made in the following manner : Plastic cement (provided by the pipe manufacturers) or a mixture of 2 parts tallow and 1 part resin is applied on the surface of the inner ring of the socket and the dovetailed ring on the spigot (see K) ; the spigot is inserted into the socket and pressed against the shoulder (see J), and waterproofed cement grout is passed down a funnel, held at one of the holes, into the groove or annular space, driving out the air until it appears at the second hole. This is an excellent joint as it is air and watertight, is quickly made, a truly aligned invert is assured, and no cement can enter the bore of the pipe.

These and similar jointed pipes are especially useful for the construction of drains in waterlogged trenches where water seriously interferes with the laying of pipes with ordinary cement joints unless pumping is resorted to.

Bituminous joints, not of the moulded ring type, are also made by using hot bitumen as the jointing material. This gives a more elastic joint than that made of cement, but it is not often used.

FOUNDATION.—A drain must have a firm foundation, otherwise settlement may occur and cause cracked or broken pipes, cracked joints, an irregular invert, etc. The Model Bye-laws require that ware pipes within " a distance of 50-ft. from a building shall be laid on a bed of concrete unless the nature of the soil renders this unnecessary." In best work a concrete bed is provided even if the ground is firm. This bed should be 6-in. thick (or not less than the internal diameter of the drain) and from 8 to 12-in. wider than the internal diameter of the pipe. It is then benched or flaunched to midway up or to the crown of the pipe, as shown at M and N, Fig. 29 (see p. 78 and C and H, Fig. 31).

CONSTRUCTION OF DRAINS

Both the (1) *boning* and (2) *gauge-board* methods are adopted in the laying of drains.

The following is how these methods are applied to a drain which is laid directly on the ground. The construction of a drain is proceeded with, commencing at the lower end, after the trench has been excavated and the bottom formed to the required gradient as described on p. 75. The sockets are therefore facing upwards and against the flow. As the barrels of the pipes should have a firm bearing on the solid ground, it is necessary that holes be formed in the bottom of the trench under the sockets (see E and F, Fig. 29). These are formed as each pipe is laid, sufficient earth being removed by the pipe layer to enable him to get his hand under the sockets to form the joints.

1. *Boning* is the more accurate method. The boning rod used is similar to that referred to on p. 75, except that it is provided with a projecting wood or metal shoe as shown at B, Fig. 29. It is held on the invert of each pipe in succession, as indicated at E, any adjustment of the pipes being made until the head coincides with the line of sight. Thus, the position of each pipe is fixed independently and therefore any errors are not accumulative. The formation of sinkings under the sockets as mentioned above is often omitted, and instead a brick is placed under each barrel near the socket ; this is an undesirable practice as such partially supported pipes may be fractured by the weight of the earth above or by traffic. The pipes are jointed as described on p. 75. Any cement which may have entered the drain must be removed before it has set. This is done immediately each joint is made by using a wood scraper Q or scraper R (consisting of a disc of rubber bolted between two wood discs) or a *badger* (having two discs similar to R with a steel spiral spring between) or a bag containing shavings.

2. *Gauge-board or Straight-edge Method.*—This is illustrated at F, Fig. 29. The board is tapered as required. Thus, if the drain is to be laid to a fall of 1 in 40, a 5-ft. long board will be $\frac{5}{40} \times 12$ in. $= 1\frac{1}{2}$-in. deeper at one end than the other ; a thin block is nailed on the splayed edge at each end so that the board will clear the sockets. The gauge-board is used as each joint is formed, the level of the pipe being adjusted until the bubble of the spirit level is in the centre of its run when the level is placed on the board as shown. This method should only be used for short lengths and branches of drains. It is not so accurate as the boning method, for, unlike the latter, any errors are accumulative. Also, as the thickness and bore of pipes may vary slightly, it follows that the invert may not be parallel to the required gradient. Special care must therefore be taken when using this method to a drain having only a slight fall.

The gauge-board is often used without blocks, and is then laid upon the sockets ; when so applied, errors may occur by irregularly shaped and eccentric sockets. A straight edge, having a projecting screw at one end which is adjusted as required, is sometimes used instead of the gauge-board. A lath, having a small fillet attached at one end of a thickness equal to the required difference in level, is a further substitute.

SETTING OUT & CONSTRUCTION OF DRAINS

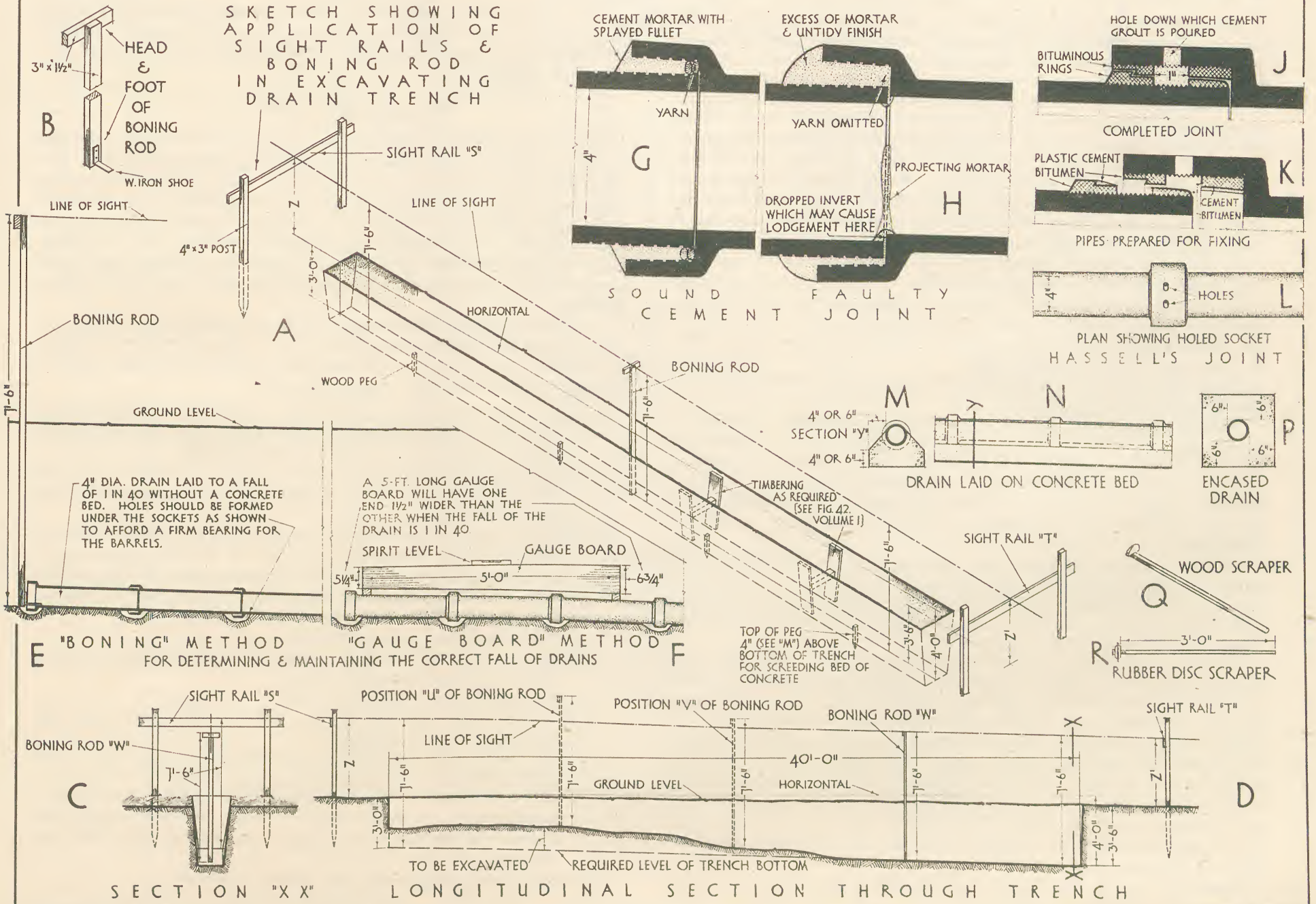


FIGURE 29

The concrete foundation for a drain referred to on p. 76 is formed in the following manner : The bottom of the trench is laid to fall as explained on p. 75, additional depth being allowed for the concrete. Wood pegs are driven in along the trench bottom at 9 or 10-ft. intervals with their tops 4 to 6-in. (according to the thickness of the concrete) above the ground. The concrete forming the rectangular bed is placed in position and screeded off (see p. 60) level with the tops of the pegs. The top of the concrete is thus given a fall parallel to the line of sight. The pipes are then laid by either the boning or gauge-board methods with their flanges resting upon the concrete. The concrete benching is formed after the joints of the drain have set, the concrete being well packed under the pipes and neatly flaunched midway up the drain pipes or to the crown (see M and N, Fig. 29). Some prefer to provide additional room for making the joints by laying the barrel of each pipe on a brick laid flat upon the concrete bed near to the socket, followed by packing and benching. A better method is to embed bricks flat at 2-in. depth and 2-ft. centres (or socket intervals) in the concrete foundation during formation ; these are removed before the concrete has set, and the holes thus formed for the sockets are filled in with fine concrete after the joints have set and during benching.

Testing Drain Pipes.—No drain shall be covered up before it has been tested and approved by the local authority.

The test most generally applied to new drains is the *hydraulic* or *water test*. Briefly, after the joints have set, the lower end is plugged, the drain is filled with water and allowed to remain for about an hour. Any drop in the water level at the end of this period (after allowance has been made for slight absorption) indicates leakage. Examination will show the cause of this. Any cracked or otherwise defective pipes are replaced by sound ones, and cracks in joints are made good.

Another test, now falling into disfavour because of the cost entailed, is the *smoke test*. Smoke from burning oily cotton waste is pumped by a machine into the lower end of the drain, the upper end is plugged, and pumping is maintained until a certain pressure is reached. Any defects are exposed by escaping smoke. These and other tests are fully described in Vol. IV.

Ball Test.—A drain may be airtight and watertight and pass either of the above two tests and yet be of defective construction owing to the presence of jointing material within the drain and an improperly aligned invert. It is for this reason that many authorities now apply the ball test to newly constructed drains in addition to the hydraulic (or smoke) test. This test merely consists of passing a solid rubber ball down each length of drain. The diameter of the ball is $\frac{1}{4}$-in. less than that of the drain. The ball is put into the drain at the top end, and if it emerges at the lower end it is a sufficient indication that the drain is true in bore and free from cement ridges. If the ball does not traverse the full length of the drain, the cause of the stoppage is ascertained and any defects remedied. This is an important test.

Refilling Trench.—After a drain has been approved, the trench should be carefully refilled in 6-in. thick layers. The finer earth is placed with care next to the drain so as not to damage the pipes and joints. This is spread and lightly consolidated, after which the remainder of the refilling is completed, each layer being well rammed.

DRAINAGE SCHEMES

The drainage plan of a building (with certain exceptions) must be submitted to and approved by a local authority before building operations are commenced. The following is usually required to be indicated on such a plan : (1) The position of rain water pipes, gullies, and the various sanitary fittings such as lavatory basins, baths, sinks and water closets ; (2) arrangement of the various drains, the sizes of which must be specified ; (3) inspection chambers, and, if necessary, the intercepting chamber (see p. 82) ; (4) means of ventilation ; and (5) the position of the public sewer (or other outlet) to which the main drain is shown connected.

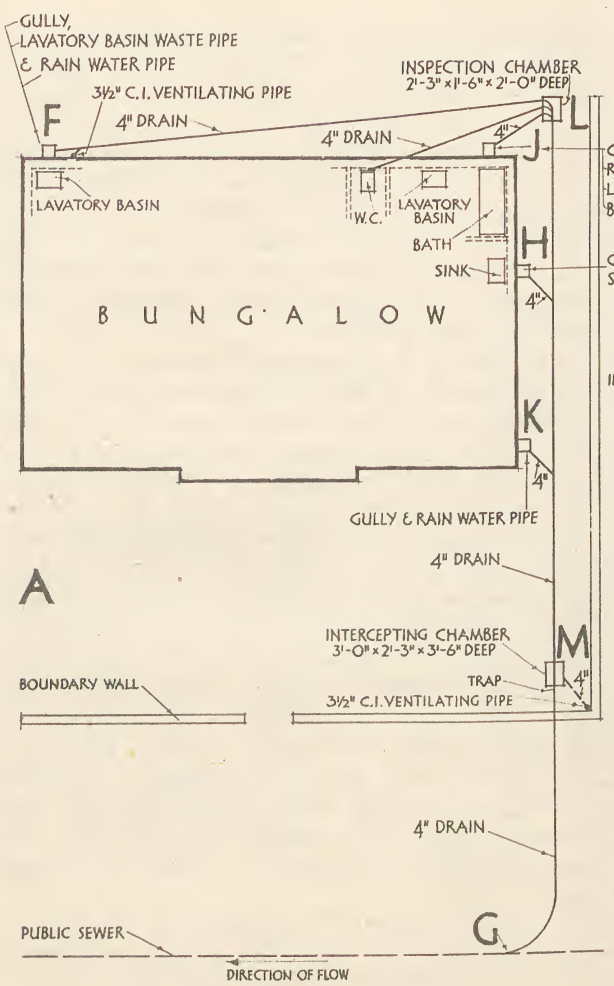
A typical plan showing the drainage scheme for a small house is shown at A, Fig. 30, and a part system is shown at A, Fig. 31. These are referred to on p. 84.

Principles of Drainage.—The essential principles of drainage applied to these and similar schemes are :—

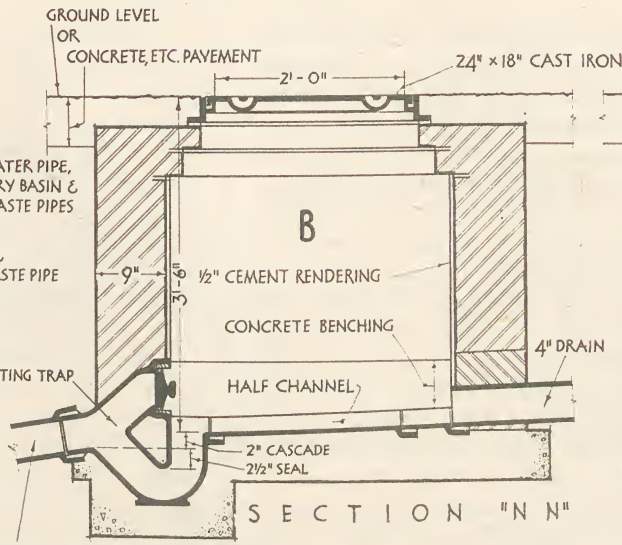
1. Drains must be airtight and watertight, constructed of sound materials and workmanship, with an even invert and a clear bore, and all traps must be self-cleansing and have an adequate seal.
2. They must be provided with a sound foundation, laid with an adequate and uniform gradient and in straight lines between points and where the direction changes.
3. Adequate means of inspection and cleaning must be provided, inspection chambers being constructed at change of direction points and in convenient positions to receive the maximum number of branch drains.
4. A drain *may* be required to be disconnected from a sewer (or cesspool) by the provision of an intercepting chamber (see p. 82).
5. Adequate ventilation must be provided.
6. Branch drains should be as short as possible and preferably laid in straight lines to the nearest inspection chamber.
7. Bends must be slow and junctions oblique.
8. Rain water pipes, and sink, lavatory basin and bath waste pipes must discharge over gullies outside.
9. Water closets must be connected direct to drains, upper water closets being connected to soil pipes which must be ventilated.
10. Unless unavoidable, no drain shall pass under a building. If laid under a building, the drain must be either of ware completely encased with concrete not less than 6-in. thick (as shown at P, Fig. 29) or be constructed of cast iron.

Several of these principles have been already referred to.

DRAINAGE SCHEME



PLAN OF DRAINAGE SYSTEM



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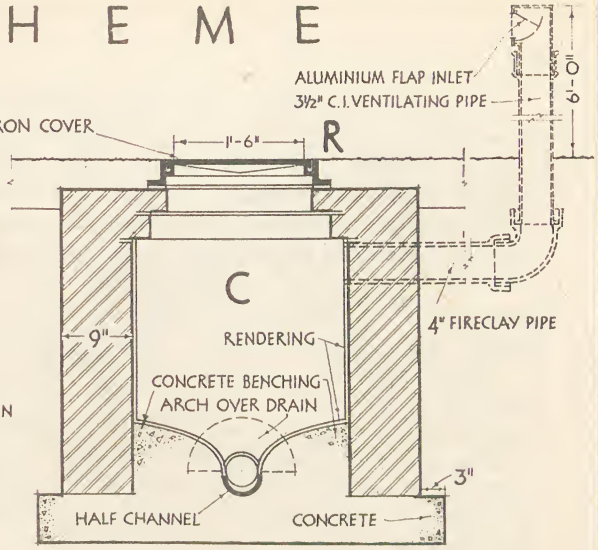

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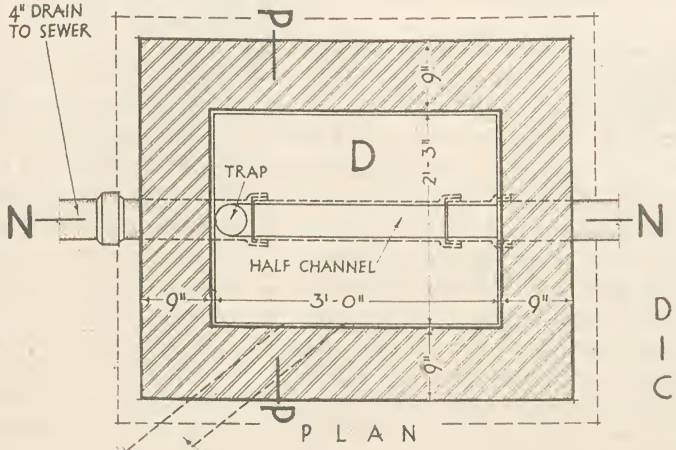
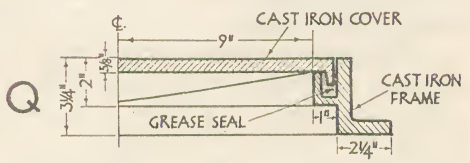
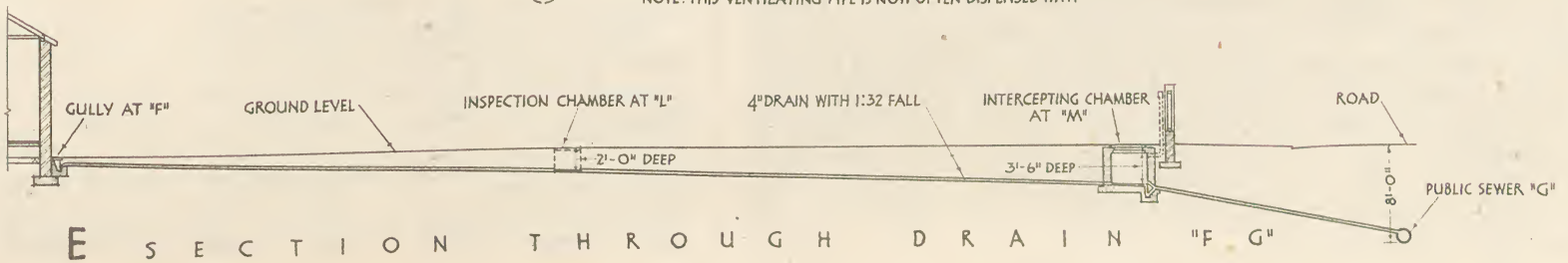


PLAN

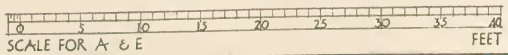


ENLARGED DETAIL AT "R"

DETAILS OF INTERCEPTING CHAMBER "M"



E SECTION THROUGH DRAIN "F G"



4" FIRECLAY PIPE
3½" CAST IRON PIPE SECURED TO WALL
NOTE: THIS VENTILATING PIPE IS NOW OFTEN DISPENSED WITH

FIGURE 30

INSPECTION CHAMBERS.—All drains should be conveniently accessible, and, in accordance with principle No. 3, adequate means of inspection and cleaning must be provided. The only satisfactory provision takes the form of a chamber such as that shown in Fig. 31. The floor is of concrete, the walls are of brick or concrete and a cast iron cover provides means of access. The minimum internal dimensions are 1-ft. 6-in. square when the depth is 1-ft. 6-in. or less, 2-ft. 3-in. by 1-ft. 6-in. when the depth is 3-ft., and 3-ft. (preferably 4-ft.) by 2-ft. 3-in. when the depth exceeds 3-ft., the latter size being necessary to enable a man to pass down and do any operation required.

The concrete floor is 6-in. thick and this need not project more than is necessary to enable the walls to be constructed, *i.e.*, 3 to 6-in. Brick footings are unnecessary. The thickness of the walls need only be 4½-in. when the depth is under 2-ft. 6-in., but should be 9-in. thick for deeper chambers. The 9-in. brickwork is usually built of common bricks (which should be hard and sound) in English bond in cement mortar 1 to 3, to which 2 per cent. waterproofer is sometimes added; this bond is shown at C, Fig. 31. An alternative form of wall construction is shown at H, the walls being in two separate half-brick leaves in stretching bond with a continuous ½-in. thick layer of waterproofed mortar between which serves as a watertight lining.

The drains are run in straight lines to the *internal* faces of the walls, and the channels to which they are connected are jointed and bedded in cement. The ends of the pipes through the walls may be either arched or concreted over as shown at C, Fig. 30 and C, Fig. 31, respectively; if roughly bricked round (a common practice) leaks may occur. The channels are usually of salt-glazed or white-glazed ware, but they may be formed in the concrete. Two alternative forms of branch connections at chambers are shown at B and G, Fig. 31. These show three branches delivering at the main drain. The construction at B consists of one double and one single half-round channel junction; the right-hand and lower left-hand branches are gradually curved in the direction of the flow by the provision of slow half-round channel bends (see also sketch C). The alternative plan G shows the application of three-quarter branch channel bends which provide gradual leads and prevent sewage overflowing and fouling the bottom of the chamber; they are particularly effective when the curvature is sharp; as shown, the inverts of these bends are above that of the half-round main channel, as their lower ends are supported on the top edges of the latter (see also sketch H). A selection of standard three-quarter branch channel bends, alternative to those at G and H, is shown at J. The spaces between the channels are filled in with concrete and this is sloped or *benched* up as shown at B and C, Fig. 30 and C, Fig. 31. The object of the benching is to prevent fouling of the base from discharges from the branch channels. Sometimes the benching is given a slope of 45°; this is rather excessive, as a workman can only stand upon it with difficulty. The form of benching recommended is that shown at C, Fig. 31, although that indicated at C, Fig. 30 is adequate when the chamber only accommodates the main channel.

The chamber must be watertight to prevent leakage of sewage in the event of the main drain below it becoming choked. For this reason it is usual to *render* the inside of the walls with a cement mixture composed of 1 part Portland cement and 2 parts sand; a 2 per cent. waterproofer is sometimes added to the mix. The thickness of this rendering should be from ½ to ¾-in., and it should be continued from the top and over the benching to the inner edges of the channels as shown; it should be trowelled smooth. Chambers over 3-ft. deep are sometimes rendered up to that height, above which the joints are neatly pointed with cement mortar. Rendering is not required when, as occasionally used in first-class work, salt-glazed or white-glazed or blue Staffordshire bricks are employed for the internal facing of a chamber.

Access to the chamber is provided by a *galvanized cast iron cover with frame*. These are of many different patterns and of various strengths and sizes. They must be large enough to allow a man to pass through, common sizes being 24-in. by 18-in. (see B and C, Fig. 30, and C, Fig. 31) and 27-in. square in the clear. The cover for this purpose must be airtight, and therefore the joint between the frame and cover has either a single, double or triple seal. A single seal joint is shown at Q, Fig. 30, the groove in the frame being filled with grease into which the lower rim of the cover projects; a band of solid rubber, known as a *rubber ring*, may be used instead of the grease to form a seating for the rim. Both of these materials may be used, thus a double seal cover may have the outer groove filled with grease or tallow, and the inner groove fitted with a rubber ring or tarred cord. If required, the cover may be locked, four gun-metal screws being used for this purpose. The top of the brickwork is corbelled over as shown, and the frame is bedded in cement mortar on it, the face of the cover being brought level with the surface of the ground or pavement. Unless the adjacent surface is paved, a 6-in. wide concrete curb, rendered smooth in neat cement, should be provided as a margin to the frame (see C, Fig. 31); this covers the flange of the frame and keeps it in position; a rebated hard stone curb serves the same purpose.

Chambers which exceed 3-ft. in depth should be provided with *step-* or *foot-irons*. These may be of galvanized cast iron, horse-shoe shaped, as shown at C and D, Fig. 31, and fixed at every fourth course, or they may simply consist of 1-in. by ⅜-in. flat wrought iron bars (dipped in hot bitumen to preserve them) fixed at vertical intervals across one of the corners. They should be well bedded in to make them secure and prevent leakage.

RODDING.—As implied, inspection chambers are provided as convenient means of inspecting, testing and cleansing drains. In the event of a drain becoming choked, the cause of the stoppage is removed by the application of *cleaning rods* (also known as *clearing rods* or *drain rods*). A rod consists of a bundle of malacca canes or Sarawak bambo canes (or ¼-in. diameter bronze rods) in 2 to 6-ft. lengths; these lengths are screwed together by means of locking joints. Several varieties of tools are available for screwing to the first length, such as screws, plungers, rollers, brushes and scrapers for the withdrawal of obstruc-

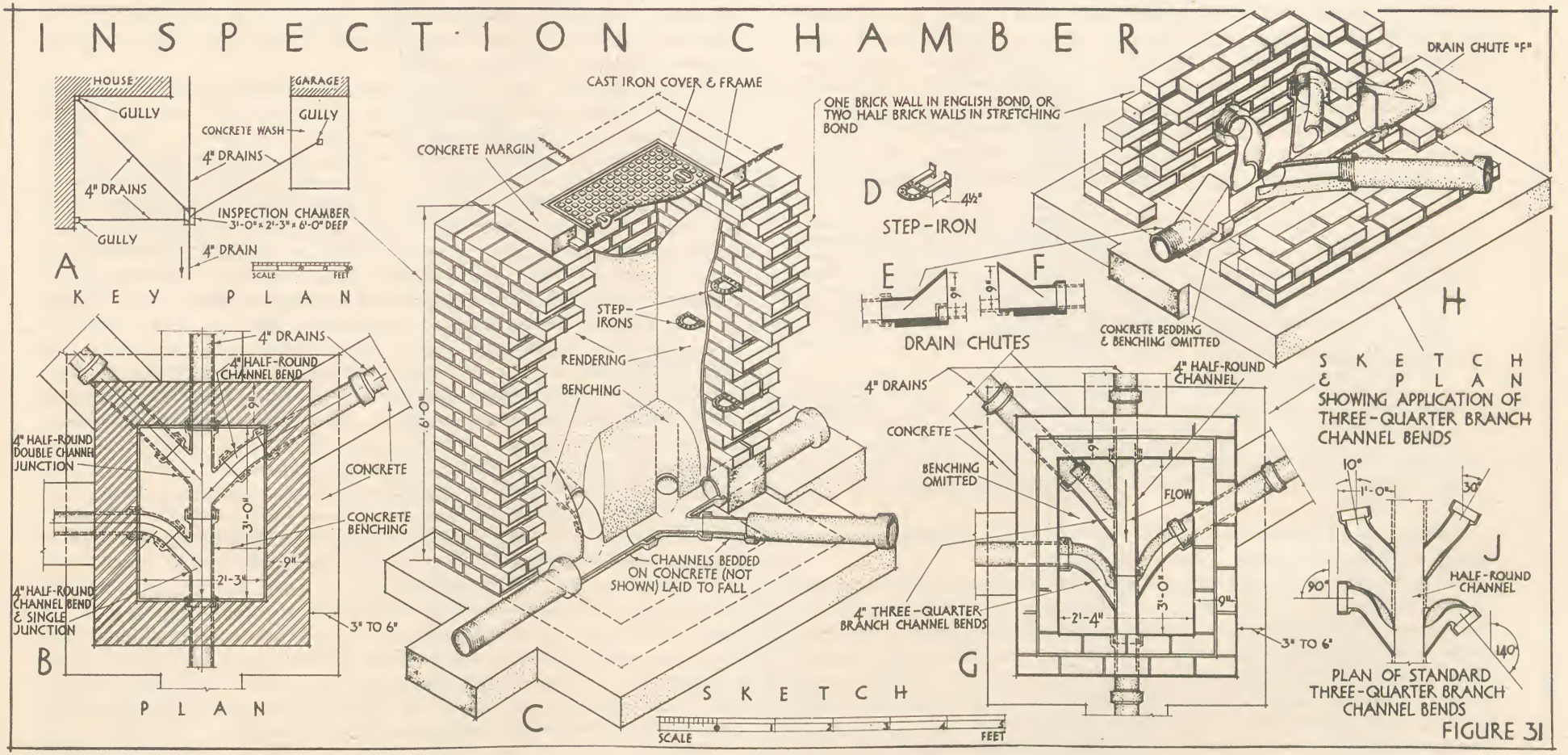


FIGURE 31

tions and the removal of grease, etc. which tends to accumulate on the internal surface of the drains.

In small deep chambers especially, the insertion of a drain rod is facilitated if a ware *drain chute* is provided. An application of these is shown at H, Fig. 31, type E being fixed at the exit and type F at the entrance of the main drain.

INTERCEPTING OR DISCONNECTING CHAMBERS.—Principle No. 4 refers to drain disconnection. An intercepting chamber is similar in all respects to an inspection chamber except that an intercepting trap or interceptor is fixed to the drain at the lower end of the chamber for the purpose of disconnecting the sewer gases from the drainage system. Of course, it also provides means for inspection and rodding. The position of such a chamber should be on the line of the main drain and as near as possible to the boundary. Plan and sections of an intercepting chamber are shown at B, C and D, Fig. 30. The trap has been referred to on p. 74, one type being shown at L, M, N and P, Fig. 28, and a somewhat similar form is shown at B and D, Fig. 30. The seal in each case is 2½-in. and the water level is 2 to 3-in. below the channel invert. This drop is called the *cascade* and its object is to increase the velocity of the sewage during its passage through the trap. This cascade cannot always be obtained owing to the available fall from the head of the drain to the sewer being inadequate, and therefore under such conditions a trap having the outlet level with the inlet is used. The latter form of interceptor is a frequent cause of stoppage in a drain, especially if the drain has less than the required minimum fall, owing to the

resulting inadequate scour through the trap leading to an accumulation of solids. The trap is provided with a *clearing arm* (also called a *raking arm* or *cleaning arm*) through which a drain rod can be passed to clear any obstruction between the trap and sewer. A *stopper* or *cap* is fitted to the arm. There are several types of stoppers, including (1) a simple ware disc which is cemented to the socket; (2) a ware disc having a bituminous rim, which, when smeared with grease or a non-setting composition, is fitted to a similar bituminous ring on the socket of the arm (see M, N and P, Fig. 28); (3) a cap which is screwed to the socket to form a bituminous joint; and (4) that shown at L and known as a *releasing stopper*.

The latter is the best form. The body of the fitting is cemented into the socket of the arm; the stopper is tightly forced in position by means of a lever which engages in slotted projecting lugs; a chain is attached to one end of the lever and passes through a staple fixed near the top of the chamber. It is an airtight stopper; it cannot be forced out by pressure of gases in the sewer, and in the event of the trap becoming choked and the chamber filled with sewage, the latter is caused to escape down the raking arm by jerking the chain and releasing the stopper; otherwise, unless the obstruction can be removed by prodding the trap, the sewage can only be removed by baling or pumping.

None of the above stoppers (1), (2) and (3) can be removed like the releasing stopper to empty a chamber filled with sewage. In addition, when stopper (1) is cemented in, it is difficult to remove without causing damage; if left uncemented (as is general) the joint is not airtight and the cap is readily forced out, by excessive pressure of sewer gases, into the trap to cause stoppage of the drain. Stopper (2) is an improvement upon (1) as it is easily removed when required and the joint is airtight; it has, however, a similar defect in that it can be forced out by back pressure from the sewer.

The trap has a flat base, and it is set correctly by means of a spirit level placed upon the " true levelling edge " (see P, Fig. 28).

Formerly, most local authorities insisted upon the disconnection of house drains from sewers by the provision of intercepting traps. *In many districts now, however, the use of such traps is optional, and an increasing number of authorities advocate their abolition* for the chief reasons that (1) the trap is liable to become choked, preventing the escape of the sewage and its ultimate overflow at the gullies; (2) the air in soundly constructed sewers is not more harmful than drain air, and disconnection therefore serves no useful purpose; and (3) increased ventilation of the whole sewerage and drainage system results when interceptors are omitted. The generally accepted view now is that interceptors are unnecessary if the sewers are properly constructed and adequately ventilated, but such traps are essential if the sewers are neither self-cleansing nor suitably ventilated.

Both inspection and intercepting chambers are commonly referred to as *manholes*, but this term should not be used in connection with house drainage owing to its ambiguity.

VENTILATION.—Drains must be efficiently ventilated (see principle No. 5), and the Model Bye-laws require that " at least *one* ventilating pipe " shall be provided to a drainage system as far as possible from the connection to the sewer. The chief aim in drain ventilation is to reduce the pressure of the foul air within the drains by providing for its discharge into the open where it will not cause a nuisance or endanger health; otherwise the accumulation of the gases may be such as to unseal traps and thereby permit of the escape of noxious air into buildings or at the ground level.

The simplest and most effective means of ventilation, generally accepted up to within recent years (see below), is to provide an inlet at the lower end of the drain and an outlet at its upper end or head. The inlet is usually a short length of ware pipe taken from near the top of the intercepting chamber and continued by a vertical cast iron pipe, 5 or 6-ft. high, fixed to the boundary wall or fence; this is finished with a head having a louvred opening, behind which is a hinged aluminium or mica valve or flap (see C and D, Fig. 30). The outlet is a cast iron pipe provided at the head of the drain. Such an outlet ventilating pipe is shown at F, Fig. 30; this would be fixed to the wall of the building and continued at least 2-ft. above the eaves and distant from dormer, etc., windows (as at D, Fig. 32); its foot would be connected to the 4-in. by 4-in. junction in the main drain by means of a 4-in. diameter bend. Thus, air entering the drain through the valve at the lower end traverses the drain before escaping at the head. *In practice, however, the INLET pipe is often found to be an unsatisfactory feature owing to the valve becoming either stuck or damaged or detached, and thus acting as an outlet. It is for this reason that many local authorities do not now insist upon the provision of ventilating inlets, and existing inlets are often abolished, especially if they are adjacent to buildings or public footpaths.* The bye-laws state that the minimum internal diameter of a ventilating outlet shall be 3-in. and that the open end shall be protected against obstruction, such as a bird's nest, by the provision of a spherical galvanized iron (or copper) wire cage (see D. Fig. 32). As a ventilated soil pipe (see D, Fig. 32) acts as an outlet it may serve as the required outlet provided it is situated near to the head of the drain. It is not practicable to ventilate every branch drain, and this is an additional reason why branches should be as short as possible (see principle No. 6). In addition to the outlet at the head of the drainage system, many local authorities insist upon the provision of a ventilating outlet at the head of every branch drain which exceeds 30-ft. in length.

DISCONNECTION OF RAIN WATER PIPES AND WASTE PIPES (see principle No. 8).—Rain water pipes must not be utilized to ventilate drains. They must not therefore be connected direct to a drain but must discharge over gullies (see pp. 72 and 74).

Waste pipes from sinks, lavatory basins and baths must discharge over gullies outside (p. 72). In addition, and in accordance with the Model Bye-laws, each of these waste pipes when it exceeds 6-ft. in length must be provided with a suitable trap. The object of such traps is to prevent the entrance of gases from decomposing organic matter which coats the inside of the pipes; many local authorities insist upon all waste pipes being trapped, irrespective of their length.

These requirements are illustrated in Fig. 32, thus:

A trapped sink waste is shown discharging over a gully at A. The standard

SANITARY FITTINGS

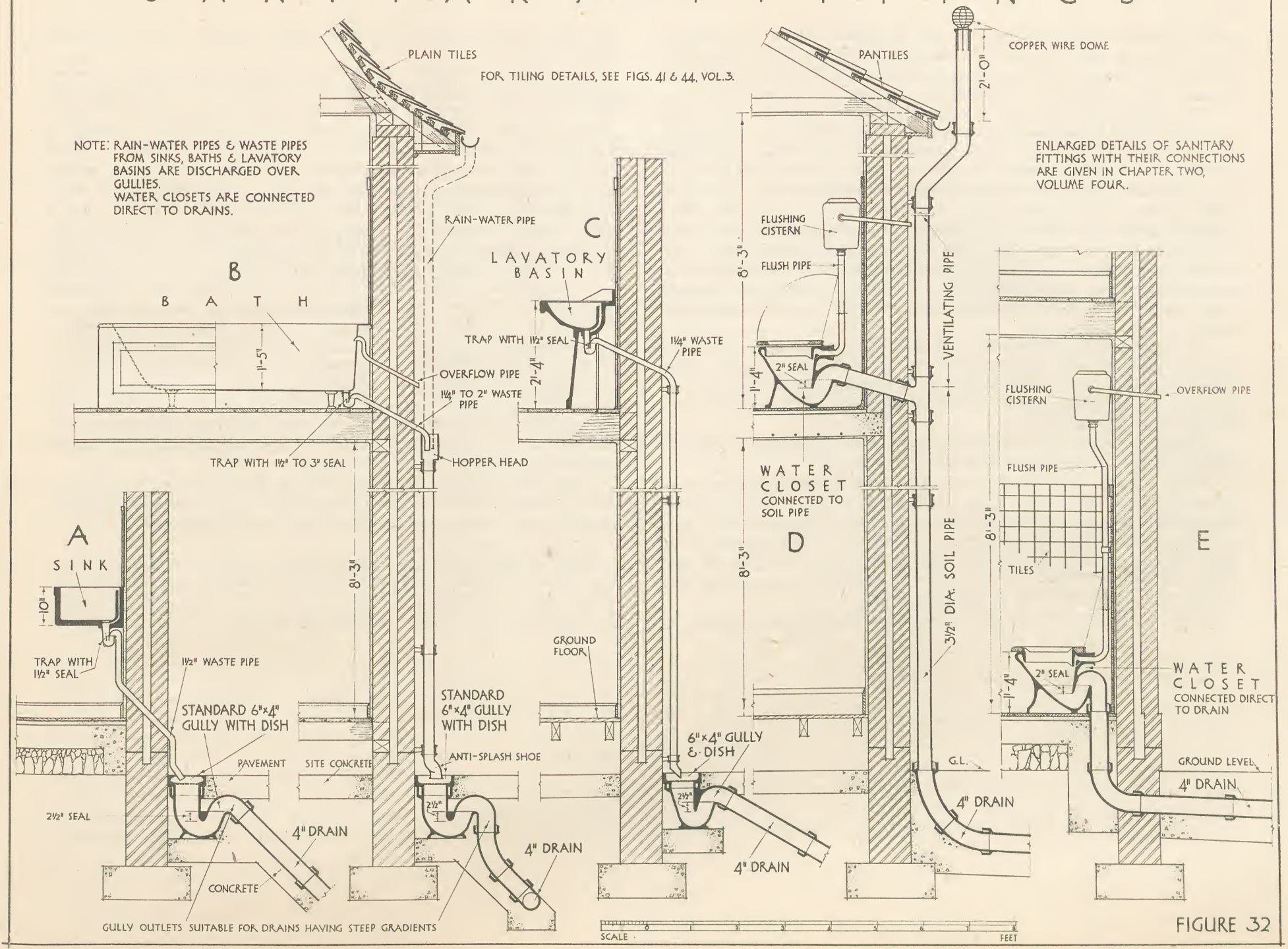


FIGURE 32

gully is bedded upon 6-in. of concrete, and its outlet is curved, as an alternative to that at Q, Fig. 28, in order that the upper end of the drain (especially if subjected to overhead traffic) may have increased cover and protection, and to provide a good connection to a branch drain having a steep gradient.

The trapped bath waste pipe at B discharges into a hopper head of a rain water pipe which is disconnected over a gully at the ground level. This gully is in the form of an S trap and is suitable for a short branch pipe to the drain shown. It will be observed that, because of the depth and close proximity of the main drain, this branch drain consists of a slow bend and a short pipe which is cut to the required length to fit the junction at the main drain. Economy results if, as shown by broken lines at B, drainage from the roof is provided by the rain water pipe which delivers into the hopper head. The anti-splash shoe shown is effective in preventing fouling of the adjacent paving, etc., which often occurs when the ordinary type of shoe is provided, and especially when a large volume of water is discharged from a bath at a high velocity (see p. 72).

The trapped lavatory basin waste pipe shown at C is connected to a vertical pipe which is continued to the ground level where it delivers over a gully. Some authorities require such a vertical pipe to be continued above the connection and (like the ventilating pipe at D) terminated above the eaves. This is an alternative arrangement to B.

These waste pipes are of lead or copper, and the traps are provided with cleansing screws to afford means of access when required.

WATER CLOSETS.—These must be connected direct to drains (see principle 9). There are many types of these fittings; those shown at D and E are of the *wash-down pedestal* type, and have a 2-in. seal. If situated on the ground floor, as at E, it is usually connected to the drain by a bend. A pedestal provided on an upper floor, as shown at D, must be connected to a cast iron or lead *soil pipe* which is jointed to the drain and its upper end is continued as a ventilating pipe terminating at least 2-ft. above the eaves (see p. 82).

These various sanitary fittings are included here in order to make the description more complete. They are not usually studied in detail in the second year of a course.[1]

DRAINAGE SYSTEMS SHOWN IN FIGS. 30 AND 31.—A drainage plan of a small one-storied house is shown at A, Fig. 30. It complies with the principles laid down on p. 78. The gully at F receives a rain water pipe and the lavatory basin waste pipe, and the 4-in. drain from it is laid with a uniform gradient of 1 in 32 to the inspection chamber L. The water closet is connected direct to the drain which is also taken to the chamber. A rain water pipe and the lavatory basin and bath waste pipes discharge over gully J connected to a 4-in. drain. As these drains are laid in straight lines to the inspection chamber they can be easily rodded if necessary. The main drain is continued at the same gradient to the intercepting chamber M,[2] collects the short branch drains from the gullies at H and K, and proceeds with an increased gradient to the public sewer to which it is connected in the direction of the flow. A ventilating outlet is connected to the head of the system at F; *if required*, a ventilating inlet is provided at M (see p. 82). A section through the main drain is shown at E. In order to provide additional protection to the upper portion of the drain (which will be necessary if there is likely to be any traffic over it) it may either be encased in concrete (see P, Fig. 29) for two or three pipe lengths, or the drain at the connection to gully F may be given additional fall (see B, Fig. 32). Details of the intercepting chamber are shown at B, C and D and have been explained on p. 81. The construction of the inspection chamber L is somewhat similar to, but smaller than, that illustrated in Fig. 31 and described on p. 80.

A key plan of portion of another drainage system is shown at A, Fig. 31. This has been introduced to show the application of a deep inspection chamber, detailed on this drawing, and which has been already described.

[1] Details are given in Vol. IV.

[2] This has been shown as an intercepting chamber to satisfy the requirements of those local authorities who still advocate the use of the intercepting trap. As pointed out, however, on p. 82, many local authorities deprecate the use of interceptors, and therefore in those districts coming under their jurisdiction the trap may be omitted at the chamber at M which would then serve as an inspection chamber only.

CHAPTER THREE

MASONRY

Syllabus.—Formation and classification of stones ; characteristics, tests. Quarrying, mining and machine dressing. Stone dressings to door and window openings. Cornices. Stone steps and stairs.

FORMATION AND CLASSIFICATION OF STONES.—As stated on p. 33, Vol. I, rocks are divided into three principal classes, *i.e.*, (1) igneous, (2) sedimentary and (3) metamorphic. These are considered in greater detail in this chapter.

Geology, which is the science concerned with the composition, structure and history of the materials of the earth, is briefly referred to here as an introduction to a study of the rocks used for building purposes.

The basic rocks of the earth's crust were formed from material molten by intense heat at the interior of the earth. Some of this material, such as granite (see next column), was consolidated at a great depth below the surface, whilst molten paste erupted from volcanoes solidified on the earth's surface to form rocks, such as, for example, those contained in the mountains of the Lake District, North Wales and the Scottish Highlands. Other rocks were formed from fragments of minerals disintegrated from the originally formed rocks by natural agencies, such as the expansive action of frost and the expansion and contraction due to alternate heat and cold, and removed by streams to form successive layers of sand, gravel, etc. ; the pressure on the lower layers squeezed out the water and interlocked the grains, and, in addition, water charged with substances such as carbonate of lime and silica acted as cementing agents and hardened the mass of such sedimentary rocks during percolation ; examples of rocks formed in this manner are sandstones and limestones (see pp. 88-94). Marbles (see p. 96) and slates (see p. 132, Vol. I) are examples of another class of rock formed from basic or sedimentary rocks which have been metamorphosed (altered) in structure as a result of lateral (side) pressure or heat or both. Yet another class of rocks is formed from the remains of marine organisms, and certain limestones (see p. 94), consisting of shells, corals, etc., are examples of these.

A classification of the known rocks of the earth's crust is given in Table IV on p. 87.

1. *Igneous Rocks.*—These have been formed of material which has been molten by the intense heat within the interior of the earth and become solidified. They are divided into (*a*) *plutonic* rocks, (*b*) *hypabyssal* rocks and (*c*) *volcanic* rocks.

(a) *Plutonic Rocks* are igneous rocks which have been consolidated at a considerable depth below the earth's surface ; the erosion (wearing away) of the upper and softer strata has caused such rocks to appear at the earth's surface. Consolidation was gradual owing to the extremely slow rate of cooling, and such rocks are therefore completely crystalline and have a coarse-grained texture.

These rocks consist of silica in combination with bases such as iron, lime, magnesia, potash and soda, and they are classed as *acid*, *intermediate* or *basic*, according to the percentage of silica content. Thus, acid rocks have over 66 per cent. of silica, intermediate rocks have from 52 to 66 per cent. of silica, and the silica content of the basic group is less than 52 per cent.

The (i) *granites* are included in the acid group of plutonic rocks, the (ii) *syenites* and (iii) *diorites* are of the intermediate group, and the (iv) *gabbro* family forms the basic group. These are described below.

CONSTITUENT MINERALS OF IGNEOUS ROCKS.—These include quartz, felspar, mica, hornblende, augite, diallage, magnetite and pyrites.

Quartz is pure silica. The grains are hard and *extremely durable* ; they are commonly colourless, although those of granite especially may vary in colour from pink, yellow, purple, red and brown to black.

Felspar is the group of minerals which is usually the most abundant. The grains are silicates of alumina combined with one or more of the bases—lime, potash and soda. Potash felspar is known as *orthoclase* ; soda felspar or *albite* and soda-lime felspar or *oligoclase* are called *plagioclase* felspars. The colour of the plagioclases is usually white or light grey, and that of orthoclase crystals may be yellowish-pink, red or green.

Mica.—These crystals are silicates of alumina with potash or magnesia. The potash micas are silver white and have a bright lustre ; one of the most important of these is known as *muscovite*. The magnesian micas are dark brown or black, and the principal of these is called *biotite*. Mica appears as short, glittering scales or flakes parallel to the natural bed ; these flakes are therefore an indication of the position of the natural bed. The white mica is very durable, but the biotite variety is softer and liable to decomposition.

Hornblende is of the *amphibole* group and is a silicate of magnesia, lime, aluminium and iron. The colour is green, brown or black.

Augite is a modification of hornblende, it being similar in composition and colour but differing somewhat in the shape of the crystals.

Diallage is a variety of augite, green in colour, and when seen under the microscope the crystals are usually laminated.

Magnetite, or magnetic ore, has a bluish-black metallic lustre ; it influences the colour of stones.

Pyrites is another iron ore. It occurs as small yellow specks. Crystals of the " white iron pyrites " variety, called *marcasite*, readily decompose, as the pale yellow changes to white efflorescence and the sulphuric acid formed in the process sets up decay in the stone.

(a) (i) *Granite.*—There are several kinds of this crystalline granular rock and these vary in colour and texture. The chief constituents are felspar, quartz and mica, the former being predominant ; hornblende and augite are sometimes represented in addition to or in place of mica. If the mica present is the white

variety, the rock is called a *muscovite granite* ; a *biotite granite* contains the dark mica only ; when both micas are present, it is known as a *muscovite-biotite granite*. A *hornblende-biotite granite* has a hornblende and dark mica content, and if hornblende without mica is present it is a *hornblende granite*.

The colour of granite is influenced chiefly by that of the felspar. The texture is also estimated by the size of the felspar crystals ; thus, it is considered that granites containing felspar grains which exceed $\frac{2}{5}$-in. in length are coarse-grained, those having felspars between $\frac{1}{5}$ and $\frac{2}{5}$-in. are medium-grained granites, and fine-grained granites have felspars less than $\frac{1}{5}$-in. long.

Granites are extremely hard, durable and strong. Those with plagioclase felspars and dark micas are relatively less durable than granites having orthoclase felspars and light micas. As described on p. 105, granites are capable of taking a high polish and are therefore easily kept clean when employed in polluted atmospheres. Owing to their great hardness, granites are difficult to work and are thus expensive. This accounts for their restricted use for building purposes. Their very high strength and durable qualities render granites the best natural stones for resisting high stresses and severe exposure ; in addition, the rich mottled or speckled coloured appearance of certain granites make them most suitable for decorative use, as for wall and floor coverings, pillars, etc. Granites have been used on many important buildings (for plinths, external walls of lower storeys, and dressings to principal entrances, etc.), for memorials, and for engineering works (including docks, sea walls, embankments, lighthouses and bridges). In districts near the quarries, granites have been used exclusively for the construction of external walls of buildings ; thus, the external walls of most of the buildings in Aberdeen are constructed of this material. Granite, because of its hard-wearing quality, is used for kerbs of streets, and for the same reason it has been extensively employed for road setts, although this form of road paving is not now favoured on account of the noise from traffic which results when streets are laid with setts. It is also used for coarse aggregates for concrete.

The principal centre in England where granites used for building purposes are quarried are Cornwall and Westmorland (Shap). Scottish granites are worked chiefly in Aberdeenshire (the most important centres being Aberdeen and Peterhead) and Kirkcudbrightshire. The principal granite districts in Ireland are in counties Down, Dublin, Wexford and Wicklow. Norwegian

TABLE III

GRANITES

Ref. No. (see Fig. 33).	Name of Granite.	Situation of Quarry.	Name and Address of Owner.	Crushing Strength (tons per sq. ft.).	Weight (lb. per cub. ft.).	Characteristics.
2	Corrennie .	Alford, Aberdeenshire	John Fyfe Ltd., Blaikie's Quay, Aberdeen, Scotland	1700	162	A muscovite-biotite. Salmon red ; medium grained.
8	Creetown .	Fell Hill and Silver Hill Quarries, Creetown, Kirkcudbrightshire	Stewart & Co. Ltd., 25 Fraser Road, Aberdeen	1382	169	A biotite. White (when hammered) and bluish-white (when polished) ; fine grained.
64	De Lank Silver Grey	De Lank, St Breward, Bodmin, Cornwall	Cornish De Lank Granite Quarries Ltd., De Lank, Bodmin, Cornwall	1171	165	A muscovite-biotite. Light greenish-grey ; medium grained.
3	Kemnay . .	Near Aberdeen, Scotland	John Fyfe Ltd., Blaikie's Quay, Aberdeen, Scotland	1987	164	A muscovite-biotite. Light silvery-grey speckled with black mica ; medium grained.
4	Lower Persley	Near Aberdeen, Scotland	George Hall, 17 Back Hilton Road, Aberdeen	1284	166	A muscovite-biotite. Light bluish-grey ; fine grained.
1	Peterhead, Red	Stirling Hill, Boddam, Peterhead, Aberdeenshire	Heslop Wilson & Co. Ltd., Peterhead Granite Works, Boddam, Aberdeenshire	1286	175	A biotite. Brilliant red ; coarse grained.
6	Rubislaw .	Aberdeen, Scotland	Rubislaw Granite Co. Ltd., Queen's Road, Aberdeen	1099	156	A muscovite-biotite. Bluish-grey ; fine grained.
5	Sclattie .	Bucksburn, near Aberdeen	A. & F. Manuelle Ltd., 59 Marischal Street, Aberdeen	849	160	A muscovite-biotite. Light bluish-grey ; medium grained.
16	Shap . .	Shap, Westmorland	The Shap Granite Co. Ltd., Shap, Westmorland	1500	165	A biotite. Greyish-pink (" Light Shap ") and reddish-brown (" Dark Shap ") ; medium grained.
62 63	Tor Brake and Tor Down	St Breward, Bodmin, Cornwall	Wm. Nankivell & Sons Ltd., St Breward, Bodmin, Cornwall	...	163	A muscovite-biotite. Silvery-grey ; medium grained.

Table IV

CLASSIFICATION OF STRATA

This classification of the known rocks of the earth's crust shows the complete geological history divided into three great *eras*, the Eozoic (meaning "dawn of life"), Palæozoic ("ancient life)" and Neozoic ("new life"). The eras are divided into *periods* and the latter are divided into *epochs*. The mass of rock of an era is known as a *group*, the rocks of each period a *system*, and those of an epoch are referred to as a *series*. The strata are shown in correct sequence, the oldest (those in the Eozoic group) being at the bottom of the table.

Group or Era.	System or Period.	Series or Epoch.	Building Stones, Slates, Marbles, Granites, Limes, etc., Found.
Neozoic / Cainozoic	Post-pliocene	Recent Strata	...
		Glacial Beds	...
	Pliocene	Forest Bed	Gravels.
		Norwich Crag	
		Red Crag	
		Caralline Crag	
	Miocene	...	...
	Oligocene	Hamstead Beds	Clays and sands.
		Bembridge Beds	
		Osborne Beds	
		Headon Beds	
	Eocene	Bagshot Beds	Clays, sands and gravels.
		Barton Clay	
		Bracklesham Beds	
		London Clay	
		Woolwich Beds	
		Thanet Sands	
Mesozoic	Cretaceous	Upper Cretaceous	...
		Middle Cretaceous	Beer Limestone.
		Lower Cretaceous	Kentish Rag Stone.
		Upper Oölites	Portland Limestone. Limestone yielding lime.
		Middle Oölites	Limestones, including Bladon.
		Lower Oölites	Limestones, including Ancaster, Clipsham and the Bath (Monk's Park, etc.) Limestones.
	Jurassic	Lias	Limestones, including Blue Lias Stone yielding lime (see p. 20).
	Triassic	Rhætic	...
		Keuper	Sandstones, including Hollington and Red Runcorn.
		Bunter	Sandstones, including Corsehill, St. Bees, Shawk and Woolton.

Group or Era.	System or Period.	Series or Epoch.	Building Stones, Slates, Marbles, Granites, Limes, etc., Found.
Palæozoic / New Palæozoic	Permian	Upper Permian	Sandstones, including Lazonby.
		Middle Permian	Magnesian Limestones, including Anston, Linby and Park Nook.
		Lower Permian	Magnesian Sandstones, including Red and White Mansfield.
	Carboniferous	Coal Measures	Sandstones, including Appleton, Appley Bridge, Brackenhill, Heworth Burn, Springwell, Thornton Blue and Woodkirk.
		Millstone Grit	Sandstones, including Berristall, Bolton Woods, Bramley Fall, Dungeons, Dunn House, Endcliffe, Guiseley, Longridge, Stancliffe, Stanton Park and Wellfield.
		Yoredale Beds	...
		Carboniferous Limestone	English Marbles, including Hopton-Wood. Limestone yielding lime.
	Devonian	Upper Devonian	Slates, including Cornish (Delabole).
		Old Red Sandstone	Sandstones, used locally in Gloucestershire, Northumberland, etc. (see p. 89).
		Middle Devonian	Limestones, including Radford. English Marbles, including Ashburton.
		Lower Devonian	...
Older Palæozoic	Silurian	Ludlow Beds	...
		Wenlock Beds	Welsh Slates, including Corwen and Llangollen.
		Llandovery Beds	...
	Ordovician	Bala Beds	...
		Llandeilo Beds	Welsh Slates, including Festiniog and Precelly. Lake District Slates, including Buttermere, Honister, Elterwater, Kentmere and Tilberthwaite; also Burlington Quarry.
		Arenig Beds	...
		Olenus Beds	...
	Cambrian	Paradoxides Beds	...
		Olenellus Beds	Welsh Slates, including Bangor, Dinorwic and Penrhyn.
Eozoic	Pre-Cambrian	...	Mainly igneous (including Granites, see Table III). Scottish Slates from Argyll, Dumbarton and Perth.

(grey) and Swedish (grey, red and black) granites are also imported into the United Kingdom, much of it being dressed in the Aberdeen district. The distribution of granites in Great Britain is shown in Fig. 33 [1] and listed in Table III.

As indicating the composition of granite, that of the De Lank Silver Grey Granite (see Table III) consists of quartz 46 per cent., orthoclase felspar 30 per cent., plagioclase felspar 6 per cent., muscovite (white mica) 11 per cent. and biotite (black mica) 7 per cent.

(a) (ii) *Syenite.*—None of the true syenite quarried in this country is used for building purposes. It occurs in Leicestershire, Carnarvonshire, the Highlands of Scotland and the Channel Islands, where it is quarried and used for road material. A well-known syenite, called " Pearl Granite," is imported from Norway and used for plinths to shop fronts, etc. ; it has a mottled appearance, with dark green markings and light-coloured patches. Syenite is hard, durable, strong and more easily worked than granite. Quartz is usually absent, felspar is the prevalent mineral, hornblende is present, and the mica content is usually less than in granite.

(a) (iii) *Diorite.*—This occurs in Leicestershire and Carnarvonshire. It is difficult to work, and this, in addition to its dull, dark green or black colour, renders it unsuitable for building purposes. It is sometimes known as *greenstone*, and is used as road metal. *Whinstone* is the name applied in Scotland to this stone, although in certain localities this name is given to any stone which is difficult to work or to stone used in road construction. Felspar, hornblende, augite and dark mica are present, and quartz is usually absent.

(a) (iv) *Gabbro* is quarried in Cornwall, certain parts of Wales, and in the Scottish Highlands. It is rarely used for building purposes on account of its bad weathering qualities and its dull appearance. Felspar, hornblende, augite or diallage are the chief minerals of gabbro.

(b) *Hypabyssal Rocks.*—These were masses of molten material which penetrated the overlying strata, and erosion of the latter has exposed these rocks at the surface. Cooling of the masses was more rapid than with the plutonic rocks, and their texture is therefore finer. Hypabyssal rocks, like plutonic rocks, are classed as acid, intermediate and basic. The rocks of the acid group are called *quartz porphyries*, those of the intermediate group are *porphyries* and *porphyrites*, and *dolerites* and *diabases* are of the basic group. The quartz porphyries and porphyrites occur in Cornwall and Devon (when they are known as *elvans*), North and South Wales and in Scotland ; some of them readily take a polish and have been used for ornamental purposes and general walling ; they are now used chiefly for breaking up into aggregates for concrete and road purposes. The porphyrites are quarried in Leicester, Somerset, Carnarvonshire, etc. ; they are very tough and are commonly used for road metal. The dolerites and diabases have a wide distribution throughout Great Britain and are employed extensively for roads (the stone being sometimes crushed, screened, dried and coated with bitumen to form tarmacadam) and rough walling ; this stone is known in the north as " whinstone."

(c) *Volcanic Rocks* have been formed from lava poured out at the surface from volcanoes. Rapid cooling and hardening caused the material to be fine grained and of a glassy character. Their group classification are *rhyolites* (acid), *trachytes* and *andesites* (intermediate) and *basalt* (basic). They are quarried in England, Scotland, Wales and Ireland, and are employed for road construction.

2. Sedimentary or Aqueous Rocks.—This division comprises those stones which are chiefly employed for building purposes. Most of these rocks are formed of fragments of igneous rocks which have been deposited by water in layers or strata. As successive layers were formed, these sediments became hardened and consolidated by great pressure and were cemented together by sandy or clayey paste or by a chemical substance (such as carbonate of lime) conveyed by the percolating water. Other rocks of this division are formed from the remains of marine organisms (shellfish, etc.) and chemically by precipitation. The principal sedimentary rocks are (*a*) sandstones and (*b*) limestones.

(a) *Sandstones.*—These consist of grains of quartz (sand or silica, see p. 85) held together by a cement or matrix. In addition to quartz, sandstones may contain such minerals as mica, felspar, hornblende and oxides of iron (see p. 85). The texture of the stone is influenced by the size and distribution of the grains ; thus, a stone may vary from fine to coarse-grained, and be either compact or the grains may be more sparsely distributed in the cementing material. As the quartz grains are practically indestructible, the durability of sandstones and grits (see p. 89) depends chiefly upon the cementing material. With the exception of freestones (see p. 89), sandstones are highly stratified, the *bedding* or natural bed being clearly visible as a general rule. The beds vary in thickness from a few inches to many feet.

The principal cements, the composition of which varies considerably, are *siliceous*, *calcareous*, *ferruginous* and *argillaceous* ; two or more of these substances may be present in the cement. Sandstones are classified according to the nature of the binding material, thus (i) *siliceous sandstones*, (ii) *calcareous sandstones*, (iii) *ferruginous sandstones* and (iv) *argillaceous sandstones*. They may also be classified as (v) *micaceous sandstones* and (vi) *felspathic sandstones*, if either mica or felspar respectively is present in fair quantity. In addition, sandstones are classified according to the character of the grains and degree of the stratification, *e.g.*, (vii) *gritstones*, (viii) *flagstones*, (ix) *tilestones*, (x) *liver stones*, (xi) *freestones* and (xii) *York stone*.

(a) (i) *Siliceous Sandstones.*—The grains of these stones are held together by siliceous cement (silica deposited from solution in water). Such sandstones are exceedingly durable, as the silica has good cementing properties and is not attacked by acids in the atmosphere. They are very hard and are usually difficult to work. Examples of siliceous sandstones are the gritstones (see p. 89 and Table V).

(a) (ii) *Calcareous Sandstones.*—The grains are bound together by calcareous cement, which is composed of *calcite* (crystals of carbonate of lime) or a combination of carbonate of lime and carbonate of magnesia and known as *dolomite* (when they are called *dolomitic sandstones*). Whilst both calcite and dolomite have good binding qualities, they are not durable if exposed to polluted atmospheres owing to the acids attacking the matrix and loosening the grains of sand which gradually become removed by the weather. These stones are easily worked. White Mansfield is an example of a dolomitic sandstone (see p. 92).

(a) (iii) *Ferruginous Sandstones.*—The cementing material is largely ferruginous, *i.e.*, oxides of iron deposited from solution. This influences the colour (such as brown, red, brownish-yellow, etc.) of the stone. These are good weathering stones, although they may be affected by frost action in very exposed situations. Red Runcorn and Woolton are of this class (see Table V).

[1] Only some of the important quarries producing granite for building purposes are indicated here. A number of well-known quarries have been closed down because of the absence of demand, and a large number of igneous rock quarries produce stone which is used solely as road metal and for concrete aggregates,

(a) (iv) *Argillaceous Sandstones* are of inferior quality and unsuitable as building stones owing to the argillaceous (clayey) cement becoming soft when wetted by rain.

(a) (v) *Micaceous Sandstones* are those in which white mica (muscovite, see p. 85) is prominent. The mica is clearly visible as glittering flakes lying with their longest faces parallel to the bedding planes. The presence of mica thus assists in indicating the direction of the natural bed of a stone. An example is Red Corsehill (see Table V).

(a) (vi) *Felspathic Sandstones* contain felspar in subsidiary amounts. Stones of this class are quarried in different parts of the country, including Herefordshire, Shropshire and Worcestershire, and are used locally.

(a) (vii) *Gritstones* or *Grits*.—These are strong, hard and durable stones. The sand grains are often coarse and angular, giving a rough texture; and the cement is siliceous. Examples are Berristall, Bramley Fall, Dungeons, Dunn House, Stanton Park, etc. (see Table V).

(a) (viii) *Flagstones* are strongly laminated and are therefore readily split along the bedding planes. They are used as paving or flagging stones, treads of steps, etc. Many quarries in Yorkshire produce sharp, annular-grained, hard-wearing and clearly laminated stone suitable for these purposes.

(a) (ix) *Tilestones*.—These are thinner-bedded stones than flagstones and are used for covering roofs, *e.g.*, traditional in the Cotswold District (thin bedded limestone) and in Yorkshire (thin bedded sandstone). See Fig. 48, Vol. III.

(a) (x) *Liver or Knell Stones*.—These are known as " thick-bedded," and, as implied, large blocks of the stone can be obtained. Many sandstones and limestones are in this class.

(a) (xi) *Freestones* are those which are fine-grained. They have no well-defined bedding planes and can be easily dressed. Examples are Red Corsehill, Locharbriggs and Woolton (see Table V).

(a) (xii) *York Stone*.—This is a term applied to sandstones from Yorkshire, and more particularly to those from that county which are specially hard, strong and durable, and specified as being suitable for steps, sills, lintels, copings, landings, etc.

Whilst the present demand for every description of stone for building purposes is less than formerly, those of the sandstone class form one of the most valuable walling materials. The weathering properties of stones are discussed on p. 97, and reference is made to the severe test imposed on stone by sulphur acid present in smoke polluted atmospheres. It has been pointed out that the durability of sandstones depends very largely upon the cementing material (see p. 88), as the quartz is practically indestructible. Siliceous sandstones (p. 88) are therefore generally considered to be the most durable of the sedimentary rocks, as the binding material of silica is highly resistant to acid attack. The excellent state of preservation of many ancient buildings built of this stone is evidence of this. Unfortunately, city buildings constructed of sandstone often assume a drab appearance owing to the dark discoloration which results. Many sandstones are exceptionally hard, and for this reason are selected for steps, sills, etc. Some are difficult to work, but others of the freestone (see preceding column) class are good chiselling stones and are very suitable for moulded work. Sandstone is an excellent and frequently used material for road construction and concrete aggregates.

Sandstones are very widely distributed throughout the British Isles. The distribution of some of the more important quarries producing building stone is shown in Fig. 33. This does not include the large number of small quarries which are worked, often intermittently, to supply sandstone for building purposes locally.

A selection of some of the principal quarries producing sandstones used for building purposes is listed in Table V. The chemical composition of a few building sandstones is shown in Table VII. An enlarged sketch showing approximately the structure of a sandstone such as is seen under the microscope [1] is shown at A, Fig. 34. See footnote to p. 94.

Whilst granites and certain Welsh slates are obtained from the Pre-Cambrian and Cambrian systems respectively (see Table IV), much of the stone is either inaccessible, or too difficult to work or is of unsatisfactory appearance. The Ordovician system does not provide building sandstones beyond beds of flagstones which are quarried for local use. Flagstones and grits are quarried from the Silurian system and used locally. Good building sandstones are quarried from the Old Red Sandstone series of the Devonian system and used locally in counties Gloucestershire, Herefordshire, Shropshire, Monmouthshire, Northumberland, Aberdeenshire and Kincardineshire; sandstones from the other series of this system are unimportant. Several good quality building sandstones have in the past been quarried in the North of England and in Scotland from the Carboniferous Limestone and Yoredale Beds series of the Carboniferous system and used on important buildings, but they are now chiefly used locally.

The most prolific sources of best sandstones employed for building purposes are obtained from the (i) Millstone Grit and (ii) Coal Measures series of the Carboniferous system (see Tables IV and V).

(i) *Millstone Grit*.—Whilst this series of strata, consisting of regular beds of gritstone, has a wide distribution throughout the country, it has been most extensively developed in Derbyshire, Lancashire and Yorkshire, where much excellent building stone is quarried.

(ii) *Coal Measures*.—This formation is widely distributed. The chief quarries are situated in Durham, Gloucestershire, Lancashire, Northumberland, Yorkshire (where there are many), Glamorganshire, Lanarkshire and Linlithgowshire. The stone is quarried in other counties and used locally. In general, this stone is hard, durable and of a good colour.

Sandstones for building purposes from the Permian system are quarried in Cumberland (Lazonby); local stone is also used from this system in the south-west of this country. The Bunter and Keuper series of the Triassic system yield good building sandstones in Cheshire, Cumberland, Lancashire, Shropshire, Staffordshire, Warwickshire, Worcestershire and Dumfriesshire.

Building sandstones are rare in the Jurassic system. There is none of much importance in the Cretaceous strata, and stone in the Cainozoic group is too soft for building purposes.

(b) *Limestones*.—These are called *calcareous* (" limey ") *rocks*, as they consist mainly of carbonate of lime. They are formed either by (*a*) organic or (*b*) chemical agencies.

[1] A thin piece of the stone, approximately $\frac{3}{4}$-in. square with smoothed faces, is mounted (secured by an adhesive,) on a piece of glass known as a *slide*. The specimen is then reduced to the required thickness, which may be not more than $\frac{1}{1000}$-in.; this is done by rubbing it on a piece of glass on which water and an abrasive (carborundum) is applied. An examination of the slide under the microscope will show the structure of the stone.

TABLE V
SANDSTONES

Ref. No. (see Fig. 33).	Name of Stone.	Situation of Quarry.	Name and Address of Owner.	Geological Identification.		Crushing Strength (tons per sq. ft.).	Weight (lb. per cub. ft.).	Characteristics.	Porosity (per cent.) (see p. 99).	Saturation Coefficient (see p. 99).	Result of Frost Test (see p. 100).
				Series.	System.						
30	Appleton .	Shepley, Yorkshire	Wm. Hampson & Co. Ltd., Shepley, near Huddersfield	Coal Measures	Carboniferous	686	148	Blue and brown; durable, very hard and strong; hard to work	11 (see p. 99)	0·70	Undamaged
32	Appley Bridge Blue	Near Wigan, Lancashire	Walter Martland Ltd., Appley Bridge, near Wigan	,,	,,	..	152	Grey to blue; very hard and durable; fine texture; fairly easy to work	7	0·81	,,
36	Berristall .	Pott Shrigley, Derbyshire	Ashton & Holmes Ltd., Macclesfield, Cheshire	Millstone Grit	,,	278	151	Cream; durable; fine texture; free working	8	0·95	,,
23	Bolton Woods	Near Bradford, Yorkshire	Bolton Woods Quarries Ltd., Bolton Woods, Bradford	,,	,,	..	148	Brownish-grey; hard and durable; fine texture	11	0·55	,,
31	Brackenhill .	Ackworth, Yorkshire	Ackworth Stone Co. Ltd., Ackworth, near Pontefract	Coal Measures	,,	..	138	Light grey to brown; both fine and coarse texture; durable	..	..	..
25	Bramley Fall	Horsforth, Leeds	A. R. Briggs & Co. Ltd., Horsforth, near Leeds	Millstone Grit	,,	400	136	Grey to buff; very hard and durable; fine to coarse texture; rather difficult to work	18	0·70	Undamaged
19	Butler Delph	Near Blackburn, Lancashire	John Greenwood, Railway Street, Glossop	,,	,,	..	163	Buff; very hard and durable; coarse grained	..	..	..
10	Corsehill, Red	Annan, Dumfriesshire, Scotland	John Murray & Sons, Annan, Dumfriesshire, Scotland	Bunter	Triassic	636	130	Pink pastel; durable; close grained; good working	21	0·60	Weathered a little at arrises
28	Crosland Hill	Huddersfield, Yorkshire	Crosland Hill Quarry Co. Ltd., Huddersfield	Millstone Grit	Carboniferous	573	148	Creamy-brown; very hard and durable; medium grained; good working	11	0·55	Undamaged
42	Dungeons .	Birchover, Matlock, Derbyshire	James Akeroyd & Sons, Ltd., Birchover, Matlock, Derbyshire	,,	,,	612	140	Pink; very durable; fine to medium texture	15	0·66	..
17	Dunn House .	Darlington, Durham	New Dunn House Quarry Co., Winston, Darlington, Co. Durham	,,	,,	468	135	Light brown; very durable; medium grained; very free working	15	0·66	..
7	Earnock .	Auchentibber, High Blantyre, Scotland	Hugh B. Kerr, Station Road, Blantyre, Lanarkshire, Scotland	..	..	..	134	White and grey; very hard and durable; good working.	18	0·75	..
33	Edgefold .	Near Bolton, Lancashire	Jackson's Stone Quarries Ltd., Farnworth, Near Bolton	Coal Measures	Carboniferous	550	150	White to biscuit; very durable; fine grained; easily worked	9	0·67	Undamaged
45	Endcliffe .	Stanton Lees, Darley Dale, Derbyshire	Henry Deeley Ltd., Birchover, Matlock	Millstone Grit	,,	612	140	Pink and brown; very durable; fine to coarse texture	15	0·67	..
24	Guiseley .	Guiseley, Leeds	A. R. Briggs & Co. Ltd., Horsforth, near Leeds	,,	,,	..	141	White and variegated; strong, durable; even texture; free working	15	0·70	Undamaged
13	Heworth Burn	Gateshead, Durham	Tate, Brown & Co., Heworth Burn and Felling Quarries, Gateshead-on-Tyne	Coal Measures	,,	651	145	Bluish-grey; very hard and durable; fine grain; not easy to work	12	0·80	,,
49	Hollington .	Hollington and Great Gate, Stoke-on-Trent	Stanton & Bettany Ltd., Rocester, Uttoxeter, Staffordshire	Keuper	Triassic	260 (W. and S.) 289 (Red) 325 (Mottled)	133 135 138	White and salmon: very durable; fine texture; free working. Red and mottled: very durable; harder than above; free working	19	0·75	..
37	Kerridge .	Macclesfield, Derbyshire	John Wetton & Sons Ltd., Bollington, near Macclesfield	Millstone Grit	Carboniferous	580	153	Buff; very hard and durable; fine to medium texture; good working; obtainable in large blocks	7	0·90	Undamaged

TABLE V—SANDSTONES—*Continued.*

Ref. No. (see Fig. 33).	Name of Stone.	Situation of Quarry.	Name and Address of Owner.	Geological Identification.		Crushing Strength (tons per (sq. ft.).	Weight (lb. per cub. ft.).	Characteristics.	Porosity (per cent.) (see p. 99).	Saturation Coefficient (see p. 99)	Result of Frost Test. (see p. 100).
				Series.	System.						
14	Lazonby	Penrith, Cumberland	Henry Graves & Sons, Lazonby, Cumberland W. & W. Graves, 41 Chiswick Street, Carlisle	Upper Permian	Permian	..	146	"Red" (light terra-cotta) and "White" (light yellowish-pink); very hard and durable; coarse grained; difficult to work	10	0·63	Undamaged
9	Locharbriggs	Dumfries, Scotland	Baird & Stevenson (Quarrymasters) Ltd., 11 Bothwell Street, Glasgow, C.2	Bunter	Triassic	405	125	Pale salmon pink; durable; medium texture; free working; obtainable in large blocks	25	0·70	Weathered a little at arrises
18	Longridge	Near Preston, Lancashire	Thomas Croft & Sons Ltd., Blackpool Road, Preston	Millstone Grit	Carboniferous	..	145	Grey and brown; very durable: medium-grained; excellent working	12	0·75	Undamaged
39	Middlewood	Oughtibridge, Sheffield	Joseph Turner Ltd., Oughtibridge, Sheffield	,,	,,	..	..	White to snuff brown; durable; medium to coarse texture	..	..	..
35	Runcorn, Red	Weston, near Runcorn, Cheshire	The Runcorn Stone Co., Weston, near Runcorn	Keuper	Triassic	254	130	Red and mottled; durable; coarse to fine texture; easily worked	21	0·65	Weathered a little at arrises
21	Scout Stone	Halifax, Yorkshire	B. Riley & Sons (Quarry Owners) Ltd., Halifax. Yorkshire	Millstone Grit	Carboniferous	..	172	Light brown to greyish-white; hard and durable	..	..	..
11	Shawk	Thursby, near Carlisle	W. & W. Graves, 41 Chiswick Street, Carlisle	Bunter	Triassic	..	138	Red, white and flecked; very durable; fine texture; free working; very suitable for carving	18	0·68	..
12	Springwell	Gateshead, Co. Durham	Richard Kell & Co. Ltd., Springwell Quarries, near Gateshead-on-Tyne	Coal Measures	Carboniferous	..	160	Yellow; very durable; medium grained; fairly easy to work	..	..	..
15	St. Bees, Red	St. Bees, Cumberland	Tom McKay & Sons Ltd., St. Bees, Cumberland	Bunter	Triassic	393	142	Bright red; very durable; fine grained; good working	..	..	..
46	Stancliffe	Stancliffe, Derbyshire	The Stancliffe Estates Co. Ltd., Darley Dale, Derbyshire	Millstone Grit	Carboniferous	646	145	Honey to very light drab; very hard and durable; uniform texture, close-grained; good working	12	0·65	..
43	Stanton Park	Birchover, Matlock	James Akeroyd & Sons Ltd., Birchover, Matlock, Derbyshire	,,	,,	600	150	Pink and brown; very durable; fine to coarse texture	..	..	..
44	Stanton Woodhouse	Stanton Lees, Darley Dale, Derbyshire	Henry Deeley Ltd., Birchover, Matlock, Derbyshire	,,	,,	512	140	Brown; very durable; fine texture	16	0·68	..
22	Thornton Blue	Near Bradford, Yorkshire	C. Cockroft Ltd., Black Dyke Quarries, Thornton, Bradford	Coal Measures	,,	..	148	Bluish-grey; very hard and durable; fine grained; costly to work	11	0·55	Undamaged
29	Wellfield	Huddersfield, Yorkshire	Samuel Johnson & Son (Mirfield) Ltd., Crosland Hill, Huddersfield	Millstone Grit	,,	705	150	Brown; very durable; fine grained; free working	9	0·90	,,
20	West End	Keighley, Yorkshire	Chas. Barrett & Sons Ltd., Oxenhope, near Keighley	,,	,,	..	153	Brown; very hard and durable; fine texture	8	0·93	,,
38	Windyway	Macclesfield, Derbyshire	John Wetton & Sons Ltd., Bollington, near Macclesfield	..	..	608	153	Bluish-grey; durable; fine to medium grained; good working; obtainable in large blocks	..	..	..
26	Woodkirk Blue	Morley, near Leeds	George Armitage & Sons Ltd., Robin Hood, Wakefield, Yorkshire	Coal Measures	Carboniferous	672	146	Blue; durable; fine grained; good working	10	0·65	..
27	Woodkirk Brown	,,	,, ,,	,,	,,	515	142	Brown; durable; fine grained; good working	14	0·65	..
34	Woolton	Woolton, Liverpool	Morrison & Sons Ltd., Wavertree, Liverpool, 15	Bunter	Triassic	518	130	Red; durable; fine grained; good working	22	0·60	Weathered a little at arrises

TABLE VI—LIMESTONES

Ref. No. (see Fig. 33).	Name of Stone.	Situation of Quarry.	Name and Address of Owner.	Geological Identification.		Crushing Strength (tons per sq. ft.).	Weight (lb. per cub. ft.).	Characteristics.	Porosity (per cent.) (see p. 99).	Saturation Coefficient (see p. 99).
				Series.	System.					
51	Ancaster Brown Weather Bed	Ancaster, Lincolnshire	The Gregory Quarries Ltd., Ancaster, Lincolnshire	Lower Oölites	Jurassic	152	156	Brown with grey and buff mottling; not durable in polluted atmospheres; coarse grained; free working; takes high polish	..	..
52	Ancaster Freestone[1]	,,	,, ,,	,,	,,	184	157	Cream to brown; durable in non-polluted atmospheres; fine even texture; free working	6	0·83
66	Ashburton .	Newton Abbot, Devon	W. W. Jenkins & Co. Ltd., Castle Circus House, Torquay	Middle Devonian	Devonian	..	170	See p. 96	..	..
67	Beer . .	Beer, East Devon	Beer Stone Co. Ltd., Seaton, Devonshire	Middle Cretaceous	Cretaceous	162	117	White; not durable in polluted atmospheres; fine grained and compact; very easy working	30	0·77
57	Bladon . .	Bladon, near Oxford	Benfield & Loxley Ltd., 106 Bullingdon Road, Oxford	Middle Oölites	Jurassic	..	153	Light brown with traces of blue; durable in non-polluted atmospheres; in thin beds only (7-in. average)	8	0·93
53	Clipsham Big Pits Quarry	Clipsham, Rutland	Clipsham Quarry Co., Clipsham, Oakham, Rutland	Lower Oölites	,,	292	140	Pale cream; durable in non-polluted atmospheres; medium grained; free working	16	0·80
54	Clipsham Old Quarry	,,	,, ,,	,,	,,	292	150	Buff, many shelly fragments; durable, especially in non-polluted atmospheres; coarse grained; free working	..	..
59	Corngrit . .	Corsham, Wiltshire	The Bath and Portland Stone Firms Ltd., Abbey Yard, Bath	,,	,,	198	129	Light cream; durable in non-polluted atmospheres; little coarser grained than Corsham; free working	..	..
60	Corsham Down .	,,	,, ,,	,,	,,	128	129	Light cream; durable in non-polluted atmospheres; fine grained; free working	..	..
47	Hopton-Wood .	Wirksworth, Derbyshire	The Hopton-Wood Stone Firms Ltd., Wirksworth, Derbyshire	Carboniferous Limestone	Carboniferous	..	150	See p. 96	..	..
56	Hornton . .	Edge Hill, Warwickshire	Hornton Quarries Ltd., North Bar, Banbury, Oxford	Lower Oölites	Jurassic	..	132	Brown, blue and mixture of both; close grained; easily worked; takes a good polish	21	0·85
61	Monk's Park .	Corsham, Wiltshire	The Bath and Portland Stone Firms Ltd., Abbey Yard, Bath	,,	,,	224	135	Light cream to white; durable in non-polluted atmospheres; fine and even grained; free working	19	0·96
68	Portland[2] . .	Isle of Portland, Dorset	,, ,,	Upper Oölites	,,	287	138	Whitbed most suitable for general building purposes; light brown or white; durable; medium grained; good working	18	0·67 (see p. 100)
65	Radford . .	Oreston, near Plymouth	F. J. Moore Ltd., Hamilton House, Tothill Road, Plymouth	Middle Devonian	Devonian	..	172	Grey to red; durable; fine grained; free working	..	..
58	St. Aldhelm Box Ground	Box, Wiltshire	The Bath and Portland Stone Firms Ltd., Abbey Yard, Bath	Lower Oölites	Jurassic	107	126	Cream to light brown; most durable Bath stone; medium grained; free working	26	0·60
55	Weldon . .	Weldon, Northants.	F. St. B. Gregorie, Weldon, Kettering, Northants	,,	,,	..	120	Pinkish-brown; not durable in polluted atmospheres; coarse grained; easily worked	29	0·75
	MAGNESIAN LIMESTONES									
41	Anston . .	Anston, W. R. Yorkshire	James Turner & Son Ltd., Kiveton Park, near Sheffield	Middle Permian	Permian	835	149	Rich deep cream; durable in non-polluted atmospheres; fine grained; free working	15	0·60
50	Linby . .	Linby, Nottinghamshire	M. McCarthy & Sons Ltd., Bulwell, Nottingham	,,	,,	..	145	Brownish-yellow; durable, especially in non-polluted atmospheres; coarse grained; free working	17	0·50
40	Park Nook .	Park Nook, Skelbrook, Near Doncaster	H. & R. F. Knowles, Skelbrook, Doncaster, Yorks.	,,	,,	345	135	Cream; durable in non-polluted atmospheres; fine grained and compact; easily worked; suitable for carved work	23	0·80
	MAGNESIAN SANDSTONE									
48	Mansfield, White[3]	Mansfield, Nottinghamshire	The Gregory Quarries Ltd., Ancaster, Lincolnshire	Lower Permian	Permian	462	140	Creamy-yellow; not durable in polluted atmospheres; fine even grained	..	..

[1] The Ancaster Freestone is also quarried by Thompson's Ancaster Quarries Co. Ltd. (11 Elmer Street, N., Grantham) at Haydon, Near Grantham.
[2] Portland stone is also quarried by The South-Western Stone Co. Ltd. (Thessaly Road, Battersea, London, S.W.8) in the Isle of Portland.
[3] Red Mansfield stone (warm red colour due to greater iron oxide content) is also quarried.

DISPOSITION OF BUILDING STONES IN GREAT BRITAIN & IRELAND

LIMESTONES

51. ANCASTER BROWN WEATHER BED
52. ANCASTER FREESTONE LINCOLNSHIRE
66. ASHBURTON DEVONSHIRE
67. BEER DEVONSHIRE
57. BLADON OXFORDSHIRE
53. CLIPSHAM BIG PITS QUARRY
54. CLIPSHAM OLD QUARRY RUTLAND
59. CORNGRIT WILTSHIRE
60. CORSHAM DOWN WILTSHIRE
47. HOPTON-WOOD DERBYSHIRE
56. HORNTON OXFORDSHIRE
61. MONK'S PARK WILTSHIRE
68. PORTLAND DORSETSHIRE
65. RADFORD DEVONSHIRE
58. ST. ALDHELM BOX GROUND
55. WELDON NORTHAMPTONSHIRE

MAGNESIAN LIMESTONES

41. ANSTON YORKSHIRE
50. LINBY NOTTINGHAMSHIRE
40. PARK NOOK YORKSHIRE

MAGNESIAN SANDSTONE

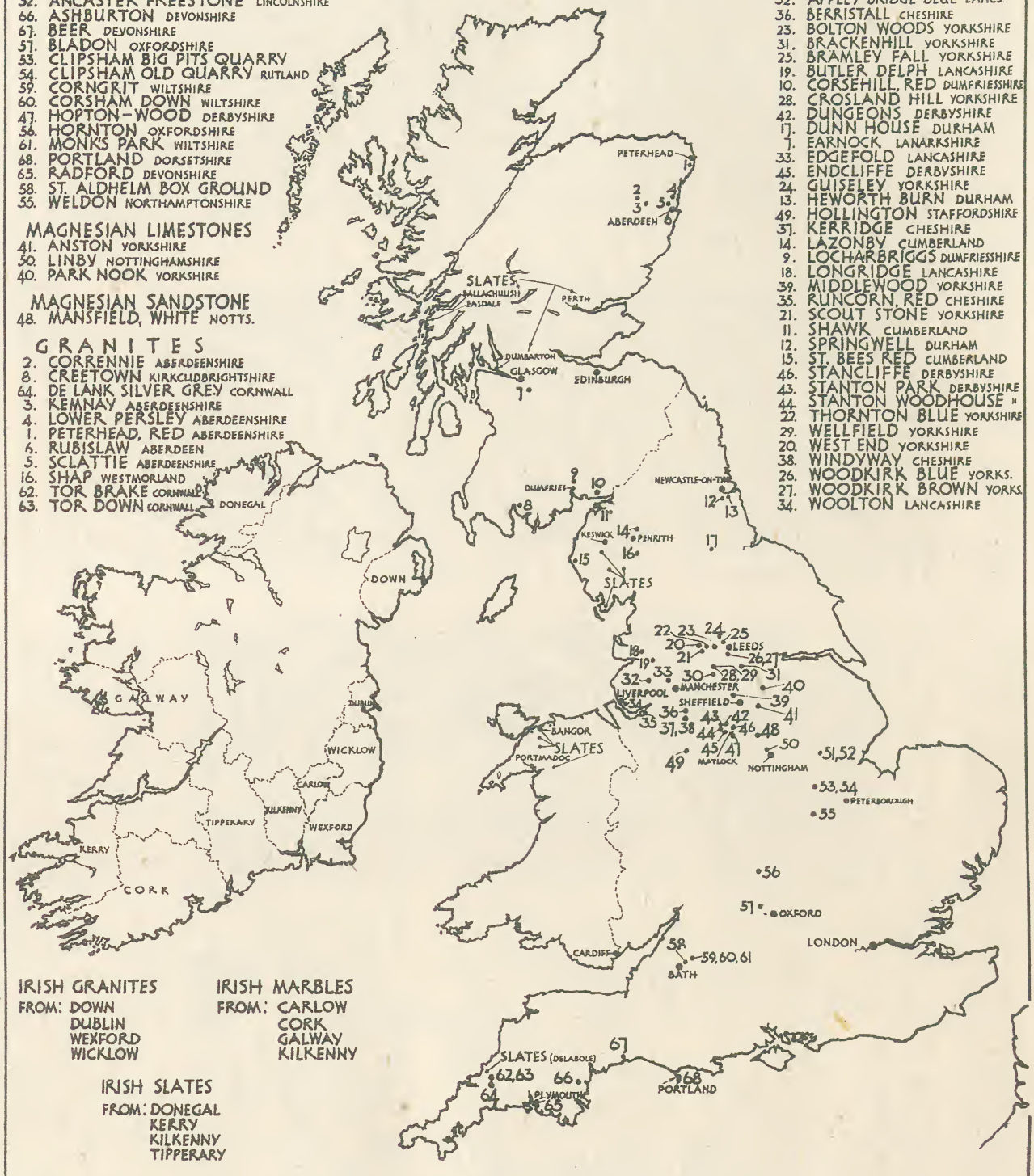
48. MANSFIELD, WHITE NOTTS.

GRANITES

2. CORRENNIE ABERDEENSHIRE
8. CREETOWN KIRKCUDBRIGHTSHIRE
64. DE LANK SILVER GREY CORNWALL
3. KEMNAY ABERDEENSHIRE
4. LOWER PERSLEY ABERDEENSHIRE
1. PETERHEAD, RED ABERDEENSHIRE
6. RUBISLAW ABERDEEN
5. SCLATTIE ABERDEENSHIRE
16. SHAP WESTMORLAND
62. TOR BRAKE CORNWALL
63. TOR DOWN CORNWALL

SANDSTONES

30. APPLETON YORKSHIRE
32. APPLEY BRIDGE BLUE LANCS.
36. BERRISTALL CHESHIRE
23. BOLTON WOODS YORKSHIRE
31. BRACKENHILL YORKSHIRE
25. BRAMLEY FALL YORKSHIRE
19. BUTLER DELPH LANCASHIRE
10. CORSEHILL, RED DUMFRIESSHIRE
28. CROSLAND HILL YORKSHIRE
42. DUNGEONS DERBYSHIRE
17. DUNN HOUSE DURHAM
7. EARNOCK LANARKSHIRE
33. EDGEFOLD LANCASHIRE
45. ENDCLIFFE DERBYSHIRE
24. GUISELEY YORKSHIRE
13. HEWORTH BURN DURHAM
49. HOLLINGTON STAFFORDSHIRE
37. KERRIDGE CHESHIRE
14. LAZONBY CUMBERLAND
9. LOCHARBRIGGS DUMFRIESSHIRE
18. LONGRIDGE LANCASHIRE
39. MIDDLEWOOD YORKSHIRE
35. RUNCORN, RED CHESHIRE
21. SCOUT STONE YORKSHIRE
11. SHAWK CUMBERLAND
12. SPRINGWELL DURHAM
15. ST. BEES RED CUMBERLAND
46. STANCLIFFE DERBYSHIRE
43. STANTON PARK DERBYSHIRE
44. STANTON WOODHOUSE "
22. THORNTON BLUE YORKSHIRE
29. WELLFIELD YORKSHIRE
20. WEST END YORKSHIRE
38. WINDYWAY CHESHIRE
26. WOODKIRK BLUE YORKS.
27. WOODKIRK BROWN YORKS.
34. WOOLTON LANCASHIRE



IRISH GRANITES
FROM: DOWN
DUBLIN
WEXFORD
WICKLOW

IRISH MARBLES
FROM: CARLOW
CORK
GALWAY
KILKENNY

IRISH SLATES
FROM: DONEGAL
KERRY
KILKENNY
TIPPERARY

NOTE: THIS DOES NOT INCLUDE MANY QUARRIES PRODUCING STONE USED FOR ROAD PAVING, COARSE AGGREGATES, &TC. AND BUILDING STONE WHICH IS CHIEFLY USED LOCALLY.

SCALE 10 0 20 40 60 80 100 200 MILES

FIGURE 33

(*a*) Those of organic origin are formed of the fossil remains of mulluscs (minute animal organisms, such as snails, furnished with shells which consist of calcium carbonate), corals, etc., that have been deposited in lakes or in sea basins, and the accumulations subsequently hardened into rocks by pressure and cementing material. These are known as *shelly limestones*, well-known examples being Ancaster, Clipsham and Weldon (see Table VI and D, Fig. 34).

(*b*) Limestones of the chemically formed group consist of grains, each having a central core or nucleus (probably a sand grain or a fragment of a shell) round which concentric layers of calcium carbonate have been deposited from water. These grains, having the appearance of eggs or roe of a fish, are called *oölites*, and the stone is sometimes referred to as " egg stone " [1] or " roe stone " (see B and C, Fig. 34). The grains vary in size, stones having large grains being called *pistolite*. Fragments of shells may be present. Portland stone and those quarried in the vicinity of Bath (*e.g.*, Corsham Down, Monk's Park and St. Aldhelm Box Ground) are well-known examples of oölitic limestones (see Table VI and B and C, Fig. 34 [2]).

The grains are cemented together by a matrix consisting of carbonate of lime, called *calcite*, or a mixture of carbonate of lime, silica, alumina and magnesia. In some cases the grains are only cemented together at their points of contact (see B, Fig. 34), in other types (see C and D, Fig. 34) the cementing material completely occupies the spaces between the grains.

Carbonate of magnesia is present in most limestones (see Table VIII). Stones containing a relatively high proportion of this carbonate are called *magnesian limestones*. If the magnesium carbonate and calcium carbonate are present in approximately equal proportions, the rocks are called *dolomites* or *dolomitic limestones* ; Anston and Park Nook are examples of dolomites (see Tables VI and VIII). A magnesian stone containing a large proportion of silica is classed as a *calcareous* or *dolomitic* or *magnesian sandstone* ; White Mansfield stone is of this type (see p. 88 and Tables VI and VII).

Limestones are used extensively for building purposes. Their weathering properties are referred to on p. 97. Many are excellent for internal work on account of their agreeable colour and free working qualities, and for external walling in districts free from atmospheric pollution. Whilst certain limestones are well established as suitable building stones and have been widely used for this purpose, others are quite unsuited for external walls of buildings in districts where acid gases are produced by the burning of coal (see p. 97).

A limestone generally considered to be well suited for external ashlar work subjected to acid attack is Portland stone. It has been employed during the past three hundred years for many important buildings in London and the provinces, and whilst the external faces are liable to become affected, the erosion is usually so slight (sheltered surfaces being possibly an exception, see p. 98) and uniform as not to be detrimental. Another reason for its popularity is the attractive appearance of light and shade produced on the weathered surfaces of this stone. As mentioned on pp. 33 and 34, Vol. I, there are three [1] beds in a Portland stone quarry which yield stone used for constructional work, *e.g.*, the roach bed, whitbed and basebed, the whitbed being most suitable for general purposes. The structure of whitbed stone is illustrated at B, Fig. 34.

Many limestones are fine grained and easily worked. Those from Bath and Beer especially are so soft immediately after being quarried that they can be readily sawn and chiselled, and their fine grain and even texture render them particularly suited for delicate carving. It is because of these characteristics, together with their agreeable appearance, that they are selected for internal ecclesiastical work such as pulpits and alter screens. Kentish Rag, a hard siliceous limestone (see p. 43, Vol. I) is not easy to work.

The distribution of certain important limestone quarries and mines is shown in Fig. 33. These limestones are listed in Table VI. The chemical composition of some of them is given in Table VIII. Some idea of the structure of limestones may be obtained by reference to the enlarged sketches at B, C and D, Fig. 34.

The Pre-Cambrian, Cambrian and Ordovician systems do not contribute any building limestones of importance. The Silurian system yields building limestones in Shropshire where it is used locally. Good limestone is obtained from the Middle Devonian series and is quarried in Devon, Ashburton (see p. 96) and Radford being examples ; some are finely veined and are of a rich colour ; the former is used for its decorative qualities and the Radford stone has been extensively employed locally, including important buildings in Plymouth, Torquay, Ilfracombe, etc. The Carboniferous Limestone series furnishes highly decorative limestone in Derbyshire (*e.g.*, Hopton-Wood) ; this takes a high polish and is classed commercially as a marble (see p. 96) ; stone from this series is used locally in Somerset and South Wales ; local use is also made in the West Riding of Yorkshire of limestone obtained from the Yoredale (or Wensleydale) Beds. Magnesian limestone occurs in the Permian system in Nottingham and Yorkshire. The Triassic system does not yield any building limestones.

The Jurassic system, especially the Oölites series, furnishes many important building limestones. A few are from the Lias series, including those quarried and employed locally in Oxfordshire, Worcestershire, Warwickshire and Glamorganshire. Ancaster, Clipsham and the Bath stones are from the Lower Oölites, and Portland stone is from the Upper Oölites series.

Kentish Rag, used for rubble masonry in the South of England, is from the Lower Cretaceous series and the white Beer stone is from the Middle Cretaceous series. As mentioned on p. 89, none of the rocks in the Cainozoic group is sufficiently hard for building purposes.

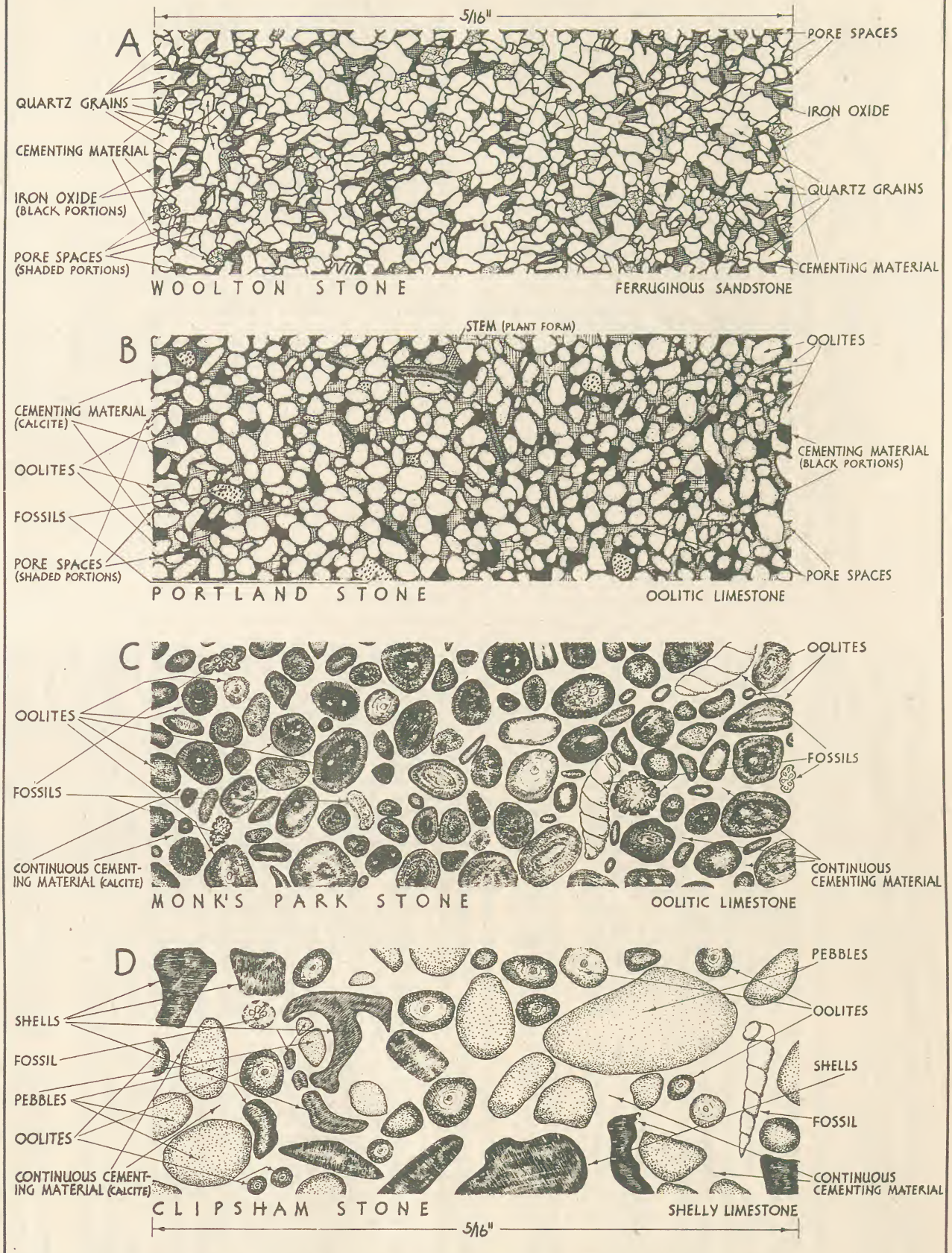
3. METAMORPHIC ROCKS.—These are either igneous or sedimentary rocks which have been altered or metamorphosed by heat (from the earth's interior) or pressure (caused by the weight of superimposed layers of material or to the

[1] Oölite is derived from *oon* = egg and *lithos* = stone.

[2] It will be observed that, in order to provide a useful comparison, A, B, C and D, Fig. 34, have been sketched to the same scale, a portion of each prepared slide being magnified and projected to permit of this.

[1] At two of the quarries worked by the South-Western Stone Co. Ltd., a bed of stone below the whitbed has been discovered which yields a highly decorative hard and compact limestone, known as " Perrycot." This is sawn into 1-in. thick slabs and is used for decorative wall linings, etc.

DIAGRAMS SHOWING TYPICAL STRUCTURES OF BUILDING STONES



NOTE: THESE DIAGRAMS, DRAWN TO THE SAME SCALE, ARE CONSIDERABLY MAGNIFIED. SANDSTONE "A" SHOWS QUARTZ GRAINS WHICH ARE ANGULAR & WELL INTERLOCKED. LIMESTONE "B" SHOWS SMALL OOLITES, FREQUENTLY GROUPED & CEMENTED TOGETHER AT THEIR POINTS OF CONTACT. LIMESTONE "C" SHOWS MUCH LARGER OOLITES WHICH ARE ISOLATED & ARE SLIGHTLY POROUS; THE CEMENTING MATERIAL IS CONTINUOUS. THE LIMESTONE AT "D" SHOWS RELATIVELY FEW OOLITES & A LARGE PROPORTION OF SHELLS & PEBBLES; THE CALCITE IS CONTINUOUS BUT PORES ARE PRESENT AT THE EDGES OF OOLITES, PEBBLES, ETC.

FIGURE 34

TABLE VII

CHEMICAL COMPOSITION OF SANDSTONES

Reference No. (see Fig. 33).	Name of Stone.	Silica.	Alumina.	Oxides of Iron.	Carbonate of Lime.	Carbonate of Magnesia.	Titanium Oxide, Potash, etc.	Soda, etc.	Water and Loss.
30	Appleton . .	92·22	2·16	2·96	0·30	0·71	...	...	1·65
32	Appley Bridge Blue	78·83	9·30	3·36	0·99	1·08	2·03	2·42	1·99
36	Berristall . .	87·00	5·20	3·10	0·68	1·00	...	1·80	1·22
25	Bramley Fall .	96·58	1·10	0·34	0·49		...	...	1·49
10	Corsehill, Red .	95·33	0·59	1·28	1·49	1·31	...	...	...
28	Crosland Hill .	87·85	4·65	2·36	0·09	0·29	0·42	2·86	1·48
42	Dungeons . .	96·40	1·30		0·36	...	...	...	1·94
17	Dunn House .	97·30	0·85		0·30	0·25	...	...	1·30
13	Heworth Burn .	86·50	5·93	2·49	1·22	0·91	...	1·95	1·00
49	Hollington . .	86·64	8·78	1·02	0·72	0·44	...	0·40	2·00
9	Locharbriggs .	97·88	0·38	0·80	0·25	0·10	...	...	0·59
48	Mansfield, White .	51·62	1·58		26·58	18·16	...	...	2·06
12	Springwell . .	86·04	8·80		0·67	0·19	...	2·30	2·00
15	St. Bees Red .	85·20	2·00	7·00	0·10	0·30	...	3·30	2·10
46	Stancliffe . .	96·40	1·30		0·36	...	...	...	1·94
29	Wellfield . .	85·78	6·98	1·73	0·73	...	...	1·57	3·21
26	Woodkirk Blue .	82·72	6·88	3·86	1·00	0·30	0·70	0·19	4·35
27	Woodkirk Brown .	83·00	8·02	3·43	0·12	0·07	0·55	0·65	4·16

TABLE VIII

CHEMICAL COMPOSITION OF LIMESTONES

Reference No. (see Fig. 33).	Name of Stone.	Carbonate of Lime.	Carbonate of Magnesia.	Alumina and Oxide of Iron.	Silica.	Water and Loss.	Remarks.
52	Ancaster Freestone .	93·59	2·90	0·80	...	2·71	
41	Anston . . .	54·88	43·08	0·73	0·56	0·75	A magnesian limestone.
67	Beer . . .	96·60	0·50	0·45	2·25	0·20	
54	Clipsham Old Quarry	97·56	0·54	0·83	0·84	0·23	
60	Corsham Down .	94·95	2·26	0·98	...	1·81	
47	Hopton-Wood . .	98·40	0·32	0·31	0·77	0·20	Referred to as a marble
61	Monk's Park . .	95·56	0·40	1·52	1·20	1·32	
40	Park Nook . .	56·10	42·20	0·50	...	1·20	A magnesian limestone.
68	Portland . . .	95·16	1·20	0·50	1·20	1·94	
65	Radford . . .	98·50	0·37	0·20	0·90	0·03	
58	St. Aldhelm Box Ground	94·52	2·50	1·20	...	1·78	
55	Weldon . . .	93·43	3·55	1·09	0·80	1·13	

movement of the earth's crust) or a combination of both. As a result of this metamorphism, the original structure of the rocks has been destroyed, the arrangement of the particles (or stratification) being changed. The chief metamorphic rocks used for building purposes are (*a*) marbles, (*b*) slates and (*c*) quartzite.

(a) *Marbles*.—True marbles are metamorphosed limestones consisting of aggregates of granular crystals of calcium carbonate (calcite). The composition varies, but some marbles comprise approximately 98 per cent. of calcium carbonate with traces of magnesium carbonate, silica and oxide of iron. Many hard, compact limestones, capable of taking a good polish, are referred to in the trade as marbles, although the metamorphosis has been only partial; examples of these so-called marbles are obtained from Derbyshire and Devonshire (see below). Marbles are obtained in a great variety of colours, some of them being richly marked or veined (due to the presence of iron oxides) and others are richly fossilized; many are finely grained and can be elaborately carved. Because of their delicacy of colouring and capacity of taking a high polish (p. 104), marbles are chiefly used for decorative purposes; they are thus employed as wall linings (the slabs being usually $\frac{3}{4}$-in. thick), pavement or floor coverings (of $\frac{3}{4}$ to 1-in. thick slabs), staircase treads, risers and balustrades, internal columns, shop fronts, fireplaces, etc.; they are also in demand for ecclesiastical work, such as altars, screens, fonts and statues.

The best known so-called marbles quarried in this country (and known as "English marbles") are Ancaster Brown Weather Bed (Lincolnshire), Hopton-Wood (Derbyshire) and Ashburton (Devonshire), although none of these are true marbles.

Ancaster Brown Weather Bed is of the Lower Oölites series (Jurassic system). It is brown with grey and buff mottling. It is coarse grained, free working and takes a high polish.

Hopton-Wood Marble.—This Derbyshire marble is marketed under five classifications, *i.e.*, (1) Light Hopton-Wood (cream-coloured ground spotted with small light brown crystals; suitable for both internal and external—if in clean atmosphere—purposes); (2) *Dark Hopton-Wood*[1] (similar to (1) but more densely marked with slightly darker patches); (3) *Black Bird's-eye* (black with slight brown cast having light coloured fossil spot markings, hence the name; only suitable for internal work); (4) *Grey Bird's-eye* (similar to (3) but of grey-brown colour); and (5) *Derbyshire Fossil* (deep grey colour, richly fossilized, some of the fossils being 2-in. long; only suitable for internal work).

Ashburton Marble—This Devonshire marble has a most attractive appearance, it being dark grey in colour, verging on black, with bright red and white crystalline veins, together with fossils.

Irish Marbles in demand in this country include: *Black* (quarried in Kilkenny and Carlow); *Connemara Irish Green* (quarried in Galway, green ground

[1] Both Light and Dark Hopton-Wood stone were used after the Great War by the Imperial War Graves Commission for 120,000 headstones.

with grey and black patches and veins); *Victoria Red* (from Cork, mottled light red with thin dark veins).

Many foreign marbles are imported and used for decorative purposes in this country, and the following are some of these :—

BELGIAN : *Belgian Black* (deep black); *Belgian Fossil* or *Petit Granite* (very dark grey with lighter grey spots—fossils—and veins); *Blue Belge* (black or deep blue-black ground with white, light grey or bluish-grey streaks); *Rouge* (various, light reddish-brown ground with white, grey or dark brown irregular veins); *St Anne* (dark grey with white cloudy patches and irregular veins).

FRENCH : *Brocatelle Jaune* (yellow with brown and white veins); *Brocatelle Violette* (purplish-grey with brown and yellow patches); *Comblanchien* (light brown with fossils); *Jaune Lamartine* (rich yellow with fine brown, grey and red veins); *Lunel* (light fawn with few markings); *Napoleon* (light fawn with brown and red veins); *Rose* (red with black veins).

GRECIAN : *Cippolino* (pinkish-white with dark green wavy bands); *Skyros* (creamy-white or delicate yellow ground with gold and purple veins); *Tinos* (dark green ground with lighter green streaks and narrow irregular black and white veins); *Verde Antico* (light and dark green mixture with occasional whitish patches).

ITALIAN : *Breccia* (grey, purple and yellow mixture with white veins); *Dove* (lavender or dark grey, slightly veined); *Fleur de Peche* (rich purple with white mottling); *Levanto Rosso* (dark red, purple and green mixture); *Pavonazzetto* (ivory ground with irregular orange and rusty veins); *Pavonazzo* (similar to Pavonazzetto with purple veins; scarce); *San Stefano* (dark buff with stippled darker flecks); *Second Statuary* (white with grey or greyish-green veinings); *Statuary* (pure white and expensive; so called as it is principally used for statues); *Sicilian* (white with bluish cast); *Sienna* (all shades of yellow with purple and black veins); *Travertine*[1] (straw, amber and golden ground with irregular darker graining; bands of small pores characteristic).

NORWEGIAN : *Brêche Rosé* (pale rose-pink ground with white mottling); *Norge Clair* (white).

SWEDISH : *Swedish Green* (pale green ground with darker green ribboning and white mottling).

Alabaster, used for ornaments, electric light bowls, etc., is sulphate of lime. It is white when in its pure form. The true alabaster comes from Algeria and has been deposited as stalactites and stalagmites.[2] So-called alabaster is found in Derbyshire, Somerset and other parts of this country.

Onyx Marbles from Algeria, Brazil and Mexico are of calcium carbonate produced as stalactites and stalagmites. They are richly figured and are of many colours, varying from white to yellow, the characteristic veining being due to the presence of metallic oxides.

Marbles are obtained from the Devonian and Carboniferous systems.

(b) *Slates.*—A true slate is a metamorphic sedimentary clay rock. Originally the clay was deposited as a fine silt; this was compressed by vertical pressure into shale, which, when subsequently subjected to enormous lateral pressure accompanied by intense heat, was converted into slate. The forces producing this side pressure contorted the original horizontal *bedding planes*, and, in addition, rearranged the particles into inclined *cleavage planes*. An example of this formation is shown in Fig. 68 on p. 133, Vol. I, and, as there described, a block of slate is readily converted into relatively thin roofing slates by splitting it along the parallel planes of cleavage. The preparation, characteristics, etc., of slates are described in Chapter Five, Vol. I.

Welsh slates are obtained from the Cambrian, Ordovician and Silurian systems. The Bangor, Dinorwic (or Velinheli) and Penrhyn slates are worked from the Cambrian (Olenellus Beds) rocks; the Festiniog (or Portmadoc) and Precelly slates are mined or quarried from the Ordovician (Llandeilo Beds) rocks; slates from Corwen and Llangollen are obtained from the Wenlock Beds (Silurian system) and are softer than most of those mentioned above (see Table IV).

Lake District green slates (Buttermere, Honister, Elterwater, Kentmere and Tilberthwaite) and those from the Burlington quarries are of the Ordovician age (Llandeilo Beds).

Cornish (Delabole) slates are obtained from the Upper Devonian series.

Scottish slates from Argyll (Ballachulish and Easdale), Dumbarton and Perth are from the Pre-Cambrian system.

Irish slates from Tipperary, Donegal, Kerry and Kilkenny are of the Ordovician age.

(c) *Quartzite* is a very compact, hard and durable metamorphic rock. Like slates, it is readily split into thin slabs, but it is very difficult to saw to panel sizes. When converted, the slabs have a very pleasing textured surface and attractive colour, ranging from grey, olive to golden. Whilst for centuries this has been used as a building material in Italy, where it is quarried, it has only recently been employed in this country on buildings as a floor and external and internal wall covering, the $\frac{3}{8}$ to $\frac{3}{4}$-in. thick slabs being bedded in mortar.

DEFECTS IN STONE

Certain defects in stone are mentioned on p. 39, Vol. I, and include clay-holes, mottle, sand-holes and vents.

DECAY of stone may be due to (1) incorrect bedding, (2) atmospheric impurities, (3) careless selection, (4) association of dissimilar stones, (5) efflorescence, (6) frost action and (7) corrodible metal fastenings. Regarding decay caused by :

1. *Incorrect Bedding.*—Serious weathering defects occur if stone is incorrectly bedded (see pp. 38 and 39, Vol. I), and especially if face-bedding (*e.g.*, with the natural bed vertical and parallel to the face of the wall) is resorted to. Blocks of stone must be built with the natural bed parallel to the pressure (see also 6 on p. 98).

2. *Atmospheric Impurities.*—A polluted atmosphere is the principal cause of decay of certain stones. Those containing calcium carbonate, such as limestones (ordinary and magnesian) and calcareous sandstones, are especially liable to attack.

The chief sources of atmospheric pollution are domestic coal fires and industrial furnaces. Such pollution occurs principally in the vicinity of large towns and manufacturing centres. The products of combustion of coal mainly responsible for decay of stone are acid gases, such as sulphur dioxide and trioxide, and soot; sulphurous acid and sulphuric acid are formed when the dioxide and trioxide respectively come into contact with water, such as rain. Although the acid gases are most concentrated in cities and industrial areas, they are

[1] *Travertine* or *Calcareous Tufa* consists of hardened masses of carbonate of lime deposited by springs; the compact variety is known as " travertine " and the light and spongy type is called " tufa."

[2] These are produced by the dropping of water containing carbonate of lime through fissures in the roofs of caves. Icicle-like stalactites (masses hanging from the roof) and stalagmites (deposits gradually built up on the floor) of calcium sulphate (or calcium carbonate) are thus formed.

readily carried by air currents and do damage for a considerable distance from the source of pollution.

When these sulphur acids descend with the rain, snow or fog upon the calcium carbonate of ordinary limestones, calcium sulphate is formed and carbon dioxide is liberated. The rain washes away the sulphate, causing *erosion* (wearing away) of the surface of the stone. The action of these acids on magnesian limestones has a similar weathering effect, the small quantities of magnesium sulphate and calcium sulphate produced are dissolved by the water present and tend to form a surface skin when the water dries out. Such erosion occurs chiefly on those external walls of buildings which are exposed to the prevailing wind (which in this country is from the south-west) and the washing action of the rain. The defect is not serious when the erosion is very gradual and uniform, and is considered by some to be an advantage on account of the different texture of wall surfaces which results. This natural washing by rain is responsible for the attractive dark and light appearance of Portland stone and similar limestone buildings.

Serious decay occurs when the sulphur acids cause the formation of a hard layer or skin on the outer surface of limestone, which subsequently blisters and flakes off, the latter condition being known as *exfoliation*. Such layers consist chiefly of salts (calcium sulphite and calcium sulphate). When the skin scales off, a fresh surface is exposed and a new hard layer is formed. Constant repetition of this process results in a weakening of the wall, and the appearance is, of course, very ugly. The decay only occurs on the surfaces of external walls which are sheltered from the washing action of rain ; exposed surfaces are not affected, as the rain removes the salts and thus prevents the formation of the surface skin. Some limestones are less liable to this form of decay than others.

Soot is a product of combustion of coal and is largely responsible for the discoloration of stone. It may also cause decay. That from domestic fires especially consists of a large proportion of tarry matter and this causes the soot to adhere to stone surfaces. Sandstones are very liable to become discoloured, and in course of time most sandstone buildings in industrial towns become black and assume a drab appearance as the pores of the surface of the stone become filled with soot deposit. Limestone buildings are not so disfigured, except those sheltered walls which are not rain-washed and on which the soot is allowed to accumulate.

Decay of stonework can be retarded very effectively if soot and dirt are removed at sufficiently frequent intervals by either washing it or cleaning it by means of jets of steam.

Stonework is washed with water from a hose pipe (such as a fire hose) connected to the water main ; a pumping machine is used if the pressure of the water is inadequate. Ladders, scaffolding or suspended cradles are required, as the stone must be scrubbed by hand with bristle brushes. An effective method for limestone buildings is to apply water in the form of a fine spray through nozzles to the stonework for one or two hours, and after a short interval the surface is lightly brushed with comparatively soft scrubbing brushes.

Steam cleaning is very effective when applied to walls which are much discoloured. The steam, generated by a boiler, is passed up a flexible tube from which it emerges on to the stone. A wire brush fitted on the nozzle of the tube is used to scrub the black surfaces.

The value of these processes in maintaining a clean appearance of buildings and arresting decay is being appreciated by an increasing number of property owners, and some buildings in towns where the atmosphere is highly polluted are washed yearly ; other buildings only require such treatment every five or six years.

The practice which is sometimes adopted of using special cleaning preparations, such as caustic soda and other alkalis, is condemned, as such chemicals damage the stonework.

3. *Careless Selection.*—Stone obtained from soft beds in a quarry or mine will weather more quickly than that from the harder beds. A wall becomes unsightly if it consists of stones which do not weather uniformly. Careful selection should ensure that only the hardest and most durable stone is used.

4. *Association of Dissimilar Stones.*—Decay of sandstones may result if both limestones and sandstones are used together in a wall. Thus, for example, a limestone string course or limestone dressings to door and window openings in a wall mainly constructed of sandstone may be the cause of decay of the adjacent sandstone ; plinths of sandstone have been known to decay because of the limestone above them.

The following is the reason for the decay : When salts, such as calcium sulphate, are formed (see preceding column), they may be washed from the limestone on to the surface of the sandstone. These salts may be absorbed and crystallize ; as an increase in volume occurs when these crystals are formed, the resulting pressure just behind the surface disintegrates the stone ; such decay may become extensive.

Similarly, when ordinary limestone is associated with magnesian limestone, decay of the former may occur due to the absorption of magnesium sulphate (see preceding column) from the magnesian limestone.

5. *Efflorescence* (see p. 13).—Decay may arise from unsuitable jointing material. The salts in cement and lime mortars may be absorbed by the stone ; crystallization of the salts may occur and either set up decay of the stone (due to the resulting pressure) or cause efflorescence on the surface. Such defects are especially likely to occur if the jointing material is a rich impermeable cement mortar, for, in wet weather, water will be absorbed by the stone and not the mortar ; as this water dries out from the stone surface only (and not from the joints), the salts are either brought to the outer face of the stone to cause efflorescence or they crystallize in the pores immediately behind it.

Brown or yellow staining of limestone walling may result from alkalis in the mortar. Discoloration of the limestone facing of compound walls may be caused from brickwork backing which is bedded and jointed with black mortar. It is desirable, therefore, that either suitable lime mortar (see p. 47, Vol. I) or asphalt be used to back the ashlar blocks, the latter being preferred, as the waterproof material effectively prevents the salts from the backing mortar penetrating the stone.

6. *Frost Action.*—This is described on p. 15 and is also referred to on p. 100. Porous and laminated stone is especially liable to decay caused during the winter by the absorption of water, which expands in the pore spaces and

bedding planes when it becomes frozen, and thus disintegration of the stone occurs. Copings, unprotected cornices and string courses, walls of unsuitable materials and inferior workmanship below the ground level, and retaining walls are most vulnerable to damage by frost action. Blocks of face-bedded stone are particularly liable, as any water penetrating the stone and becoming frozen will cause patches of the skin to spall off.

7. *Corrodible Metal Fastenings.*—Reference is made on p. 52, Vol. I, to the damage caused to stonework which is secured with corrodible metal, such as wrought iron. The expansion which occurs when embedded wrought iron corrodes is sufficient to split huge blocks of the stone, such as cornices, copings and upper spire stones.[1] Metal which does not rust, such as bronze, gun-metal and copper, should be used for these fastenings.

PRESERVATION.—The best method of preserving stone is by washing or steam cleaning (see p. 98). Most so-called " preservatives " have proved to be unsatisfactory.

TESTS APPLIED TO STONES

It is recognized that the most reliable indication of the durability of a stone required to withstand certain atmospheric conditions is obtained by a careful inspection of that used in the construction of buildings which have been subjected to similar exposure for a lengthy period. Such is not, however, a conclusive guide, as the quality of stone obtained from different parts of a quarry may vary considerably, and it does not therefore follow that the characteristics of recently won stone are similar to that obtained from older workings in the same quarry and which was used for the inspected buildings. Further, the quality of stone from a new quarry cannot be judged in this manner. Laboratory tests are therefore valuable for supplying information which could only be otherwise obtained by trial and error methods.

The following are tests which may be carried out for estimating the durability of stone : (1) Rate of water absorption or permeability, (2) percentage porosity, (3) saturation coefficient, and (4) resistance to frost. They provide information which can be compared with stones whose durable qualities and other properties are known, and whilst such comparative tests are not decisive, they do give data which may be of value when selecting a stone for a specific purpose. Students should refer to the footnote on p. 14 for brief definitions of absorption, permeability and porosity.

1. *Rate of Water Absorption or Permeability Test.*—This is described on p. 14, the brass cover being fitted to the stone specimen whose four vertical faces are rendered impermeable by the application of wax. As already explained, the test conditions are not likely to be exceeded, even in the most exposed positions, by those met with in practice.

2. *Percentage Porosity Test.*—In order to understand the significance of the expression " percentage porosity," the student should revise the definitions of *bulk density* and *solid density* which he would have considered in his study of Building Science and which for convenience are repeated here.

Density (in lb. per cubic foot) $= \frac{\text{weight (in lb.)}}{\text{volume (in cubic feet)}}$; therefore the *bulk* or *total density* (in lb. per cubic foot) $= \frac{\text{weight (in lb.)}}{\text{bulk volume (in cubic feet)}}$. If the specimen to be examined is of irregular shape, the bulk volume is obtained by using an apparatus such as the *overflow tank* shown at A, Fig. 35. The specimen is carefully lowered into the tank which has been previously filled with water to the " weir " level indicated ; the water displaced passes from the outlet into a vessel of convenient size and transferred to a glass measuring cylinder ; this gives the volume of the water, which is equal to that of the specimen.

The solid or powdered density (in lb. per cubic foot) $= \frac{\text{weight (in lb.)}}{\text{solid volume (in cubic feet)}}$.

Actually, the solid density of most stones, in addition to bricks and concretes, is approximately the same, namely, 166-lb. per cub. ft. The adoption of this figure therefore simplifies the routine, as it obviates the necessity of powdering the specimen and obtaining its volume.

The *percentage porosity* is found after the bulk and solid densities have been determined, thus :

$$\text{Percentage porosity} = \frac{\text{volume of voids}}{\text{bulk volume}} \times 100$$

$$= \frac{\text{bulk volume} - \text{solid volume}}{\text{bulk volume}} \times 100$$

$$= \left(1 - \frac{\text{solid volume} \times \text{weight}}{\text{bulk volume} \times \text{weight}}\right)100$$

$$= \left(1 - \frac{\text{solid volume}}{\text{weight}} \times \frac{\text{weight}}{\text{bulk volume}}\right)100$$

$$= \left(1 - \frac{\text{bulk density}}{\text{solid density}}\right)100$$

$$= \left(1 - \frac{\text{bulk density}}{166}\right)100.$$

The percentage porosities of the stone specimens (approximate size, 5-in. by 3-in. by 2-in.), given in Tables V and VI can be determined by using this formula. Thus, taking the Appleton stone which heads the list in Table V, the bulk density being 148-lb. per cub. ft. the percentage porosity $= \left(1 - \frac{148}{166}\right)100 = 11$ approx., the figure given in the table.

3. *Saturation Coefficient Test.*—Damage caused by frost is referred to on p. 98 Very porous stones will absorb more water than others less porous and are therefore more vulnerable to damage due to frost action. If the voids are completely filled with water and this water freezes, the resulting pressure will tend to disrupt the cell walls by internal pressure. If, however, the interconnected pores (see p. 14) are only partly filled with water, there may be sufficient space within them to allow for this expansion, and damage to the stone structure will not occur. Hence the ratio of water absorbed to the volume of void space may be taken as a measure of the capacity of the stone to resist frost action ; this ratio is known as the *saturation coefficient*. It is usually expressed as follows :—

$$\text{Saturation coefficient} = \frac{\text{water absorbed after twenty-four hours' soaking}}{\text{total water absorption after five hours' boiling}}.$$

[1] The apex of a stone spire consists of blocks of stone which are usually connected together by a central vertical metal rod. It is a fairly common experience to find that these blocks have developed cracks, and investigations have shown that the defects were caused by the corrosion of the rods. The work of restoration is costly, as scaffolding has to be erected, and the whole of the defective stonework must be removed and replaced with new blocks which are " threaded " over a non-corrodible vertical rod.

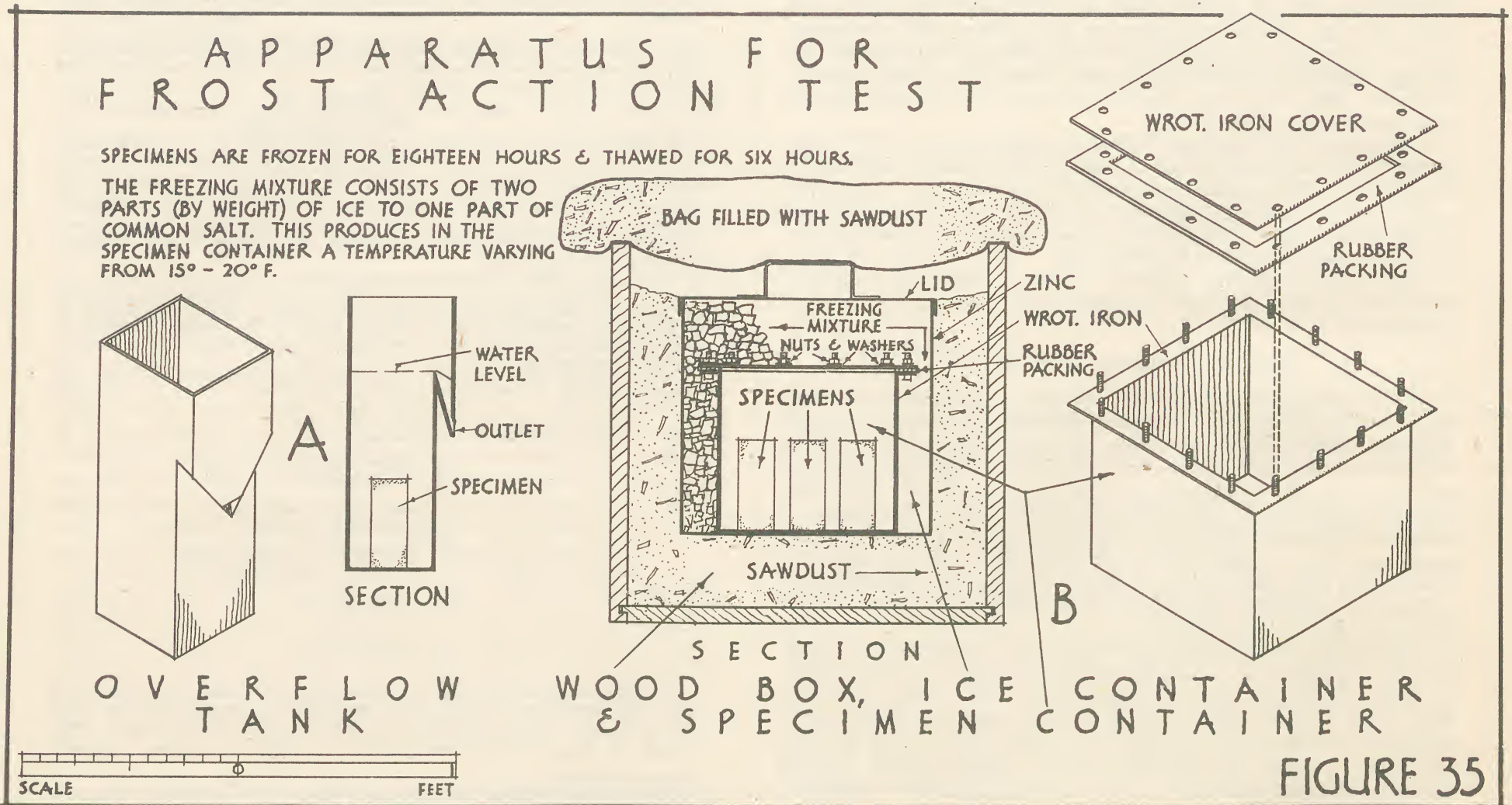


FIGURE 35

This test is carried out as follows: The stone specimen is dried in an oven, allowed to cool, weighed, soaked in cold water for twenty-four hours, removed and wiped with a cloth, and re-weighed. The difference between these two weights is that which is placed in the numerator (p. 99). The specimen is then returned to the water and boiled for five hours; it is then allowed to cool under water, removed, wiped and weighed; the difference between this latter weight and the dry weight is the figure which appears in the denominator.

The saturation coefficients supplied in Tables V and VI were obtained in this manner. Thus, taking the Portland stone listed in Table VI, the dry, soaking and boiling weights were 1,028, 1,084 and 1,111-gm. respectively, giving a saturation coefficient

$$= \frac{\text{(water absorbed after twenty-four hours' soaking)}}{\text{(total water absorption after five hours' boiling)}}$$

$$= \frac{\text{weight after soaking (1,084-gm.)} - \text{dry weight (1,028-gm.)}}{\text{weight after boiling (1,111-gm.)} - \text{dry weight (1,028-gm.)}}$$

$$= \frac{56}{83} = 0{\cdot}67 \text{ (see Table VI).}$$

This coefficient has a practical value as it is considered to be a helpful guide to the capacity of the stone to withstand frost action. As a general rule, it is regarded that a stone having a saturation coefficient of 0·80 and under should not be liable to

damage from frost action. As, however, there are exceptions to this, it is desirable to submit a stone of unknown frost resistance to a freezing test (see below).

4. *Frost Resistance Test.*—The apparatus[1] used for this purpose is illustrated at B, Fig. 35. It consists of a wood box (22-in by 22-in. by 21-in. deep of 1-in. thick timber), a zinc ice container (14-in. by 14-in. by 13-in. deep of 20 Z.G.) with lid, a wrought iron specimen container (10½-in. by 10-in. by 9-in. deep of 14 S.W.G.) with cover, and a bag filled with sawdust (or similar insulating material) as a cover to the wood box.

The test is performed in the following manner: Sawdust (or granulated cork) to a depth of about 4-in. is placed at the bottom of the wood box; the ice container is placed on top of this sawdust and this or similar insulating material is packed at the sides as shown in the section; the stone specimens are placed in the specimen container, the metal cover is tightly screwed down to ensure that the rubber packed joint is watertight, and this container is placed within the ice container. The freezing mixture is then packed in the ice container, the lid is fitted on it and, finally, the sawdust bag is placed over the outer box (see section). The freezing mixture consists of 2 parts (by weight) of ice to 1 part (by weight) of common salt. This produces a temperature in the specimen container varying from 15° to 20° F. (−9° to −7° C. approx.). The specimens are subjected to this temperature for eighteen hours, after which they are removed and gradually thawed in water for six hours; after examination, they are replaced, again frozen for eighteen hours, removed, thawed for six hours and examined. This cycle is repeated until the samples have undergone ten freezings.

The specimens listed in Table V were tested in this manner. It will be seen that some were unaffected and others showed damage at the arrises. Stone of poor quality is seriously damaged when subjected to this test, some splitting and showing similar signs of disruption after only the first or second freezing.

The weather conditions experienced in this country are not sufficiently severe to cause frost damage to stonework in general walling, unless the stones are face-bedded and the stone is of inferior quality, but coping, etc., stones are liable to disintegration if subjected to prolonged periods of rain followed by frost (see p. 99).

Other tests include a chemical test (such as subjecting the specimens in a closed tank to hydrochloric acid fumes) and that for determining the compressive strength; a machine used for the latter is shown at E, Fig. 9, and described on p. 32.

QUARRYING AND MINING

A description of quarrying appears on pp. 33 and 34, Vol. I. Open quarrying is not resorted to when building stone is at a considerable depth below the surface, as the removal of the overburden would be too costly. Beer stone and most of the limestones (including Congrit, Corsham Down, Monk's Park and St. Aldhelm Box Ground, see Table VI) obtained in the Bath district are mined. A typical stone mine consists of an adit or tunnelled opening made in the side of a hill at the level of the best stone. The adit is continued as the stone is removed and follows the bed. Branch tunnels are formed from this main gallery. In the Box Ground mine the underground workings pass from one side of the hill to the other, a distance of three miles, and the galleries in some places are nearly 100 ft. below the surface. The height of the tunnels is at least equal to the thickness of the good stone beds, which may be up to 10-ft., and the width may exceed this.

The roof and floor of a tunnel consist of hard coarse stone. The first operation in winning the limestone is to pick out the top 9-in. of the stone just below the roof; this is called the *picking bed*, and the tool used is a long-handled pick. When the picking has proceeded some 5 or 6-ft., a long hand saw is employed (which is operated at the handle by both hands) to divide the rock by vertical cuts extending from the top to the next bed and at about 5-ft. horizontal intervals; this operation is comparatively easy as the stone is very soft. A block, having three free sides, is removed either with large crow bars or by a crane, the rope from the latter being attached to a lewis bolt inserted in the face of the block. The blocks, which may weigh from 6 to 8-tons, are squared up with saws, and then lifted by the crane on to bogies which run on lines and are horse-drawn along the tunnel to the surface depot. The roof is supported at intervals by strong cross-beams supported by props at the sides; falls of the roof are also averted by the insertion of oak wedges in any vertical cracks or vents.

When Bath stone has just been removed it contains much quarry sap; it is soft, and if used immediately it would weather badly. It is therefore allowed to *season* for a period before being fixed. The time allowed for the blocks of stone to remain in the stacking ground depends very largely upon the demand, but normally the stone is seasoned for several months before being dressed. If necessary, the stone can be dressed soon after mining if obtained between the late spring to the end of September, but that mined during the winter months is stored underground till the following spring before it is worked. Damage from frost is thus prevented.

MACHINE DRESSING

A brief description of certain machines used for dressing stone is given on pp. 34 and 35, Vol. I. Some of these are illustrated here in Fig. 36.

FRAME SAW (see A and B).—This machine, which is used for sawing large blocks into several smaller slabs, has a swing frame which holds the desired number of steel saw blades. The frame is suspended by four rods, and operates with a backward and forward motion by means of a connecting rod secured to the frame and the crankshaft of the flywheel which is driven by electric or other power. The blades are either corrugated (see C) or wavy or plain in section, the former being commonly used for sandstone, limestone, slate and granite, and the plain type for marble; they are 3, 4, 5 or 6-in. wide by ⅛-in. thick (for marble), $\frac{3}{16}$-in. thick (for sandstone and limestone) and ¼-in. thick (for granite). This machine is made in various sizes, the maximum size of stone that can be dealt with varying from 8 to 14-ft. long, 4 to 8-ft. wide and 4 to 6-ft. thick.

The block of stone to be converted is placed on a bogie or trolley, packed firmly and level, and wheeled in position under the swing frame. The required number of blades is fixed in the frame at the necessary distance apart. The maximum number of blades which may be fitted to the frame depends upon the hardness of the stone and the power of the machine; generally the number does not exceed twelve, and this may be reduced to four or five blades if the stone is very hard; for marble slabbing, when the thickness of the slabs may be only ½-in., the number of blades (which are secured by special fittings) may reach thirty. The machine is set into operation causing the saw frame to descend the long worm screws in the four legs at a predetermined speed and regulated by the ratchet arrangement controlled by the levers shown at A. The rate of the downward feed is regulated according to the hardness of the stone, the number of blades used, etc.; as a guide, the cutting speeds of one 12-ft. long machine, having twelve blades, are 5, 12 and 30-lin. in. per hour for hard

[1] As used in the Department of Building, Manchester College of Technology.

sandstone, Portland stone and Bath stone respectively; a similar machine, with four blades, will saw granite at the rate of from 1 to 1½-in. per hour; for cutting thin slabs of marble, the speed is reduced to about 1½-in. per hour in order to secure the desired accuracy.

An abrasive material, such as chilled shot (steel pellets), sharp sand or carborundum, in addition to water, must be used to facilitate the sawing operation. The water is supplied from a tank situated above the machine and is automatically distributed over the stone through small taps fixed in two transverse pipes which either swing backwards and forwards with the frame or are kept stationary. The abrasive, placed as required over the cuts or kerfs in the stone by the sawyer (man in charge of the machine), is carried by the water down the cuts to the lower edges of the blades, and thus deepens the cuts during the reciprocating action of the blades; in addition, the water cools the blades and thus prevents undue wear of the steel. Steel shot is generally used for corrugated blades, except for limestone, when sand should be used, as shot rusts and would cause discoloration.

The cross-section at A shows a block of stone partially sawn into seven slabs.

On completion of the "slabbing," the frame is stopped and raised, the bogie is run clear of the frame and the stone is removed.

The frame saw is the most useful machine for cutting hard stone.

Another machine, known as the *rip saw*, is somewhat similar to the above with the exception that its width is greater than its length and the wide bogie runs on a track at right angles to that shown at B; the swing frame has thus a transverse reciprocating motion. The rip saw is usefully employed for cross-cutting blocks and especially those which are too wide for the ordinary frame saw.

Diamond Saw (see D).—This machine is used for rapidly and accurately cutting relatively small blocks of stone, such as slabs from the frame saw. It has a circular steel saw blade which is caused to rotate by an electric motor at a high speed to cut the stone which travels towards it on a moving table. The size of saw blade varies from 24 to 84-in. Saw blades must be carefully tensioned (see p. 27, Vol. III). Welded to the rim of the blade are U-shaped steel sockets or clips into each of which a half carat diamond is securely fixed; an enlargement of a portion of a blade is shown at E; the diamonds are staggered, as indicated, in order that the width of the cut is fully covered; four sockets per inch diameter of blade are provided, thus a 60-in. blade is fitted with 240 sockets provided with the same number of diamonds. The maximum speed of the blade varies with its diameter; that of a 60-in. diameter blade is 575 revs. per min. whilst a 72-in. diameter blade has a maximum velocity of 480 revs. per min. This speed is regulated according to the character of the stone, it being much less for a hard sandstone than for a soft limestone; in order to avoid damage to the arrises of the stone, the speed of the blade is lowest when the blade is just entering and leaving the block. The deepest cut that a saw blade will make is less than half the diameter of the blade, thus, for example, the maximum depth of cut of an 84-in. blade is approximately 3-ft. and the thickness of stone would be restricted to this.

A water feed, necessary to cool the blade, is provided as shown at D. The pipe can be raised or lowered as required to deliver water on top of the stone. A guard is fixed to the upper half to prevent splashing.

The stone is placed upon, but not necessarily fixed to, a cast iron table which moves on rollers. After the blade has been brought to the required position by traversing the frame, the table is advanced quickly to bring the stone up to the blade and proceeds at the desired speed until the cut has been formed, after which the table is quickly returned. The machine has four changes of feed for cutting, in addition to the quick advance and return, and these changes are readily effected by the sawyer operating a lever.

The cutting speed depends upon the horse-power, hardness of the stone and depth of cut. A 30 h.p. machine will saw a 3-ft. thick block of Portland stone at the rate of 216 sq. in. per min. of sawn area. This rate is much higher than that of the frame saw, but whilst the latter can deal with all types of stone, including granite, a diamond saw is only suitable for relatively soft stones, such as limestones, as hard stones would quickly damage the blade and wear out the sockets.

The machine can also be provided with two tables which can be either used together or one can be loaded whilst the stone on the other is being cut.

This machine may also be provided with two circular saw blades, when it is called a *twin blade* or *duplex machine*. It has either one or two tables, the latter moving on separate tracks parallel to each other. The blades, with a lateral movement, are independent and may be traversed in the same or opposite direction as required. These blades can be raised or lowered (known as a *rising and falling motion*) and are thus invaluable for forming cuts less than the thickness of the stone (an operation called *checking*) as required for grooves in window sills, etc., for *channelling* (removal of portions of the backs of stones such as are required to be fixed to steel beams and pillars of steel-framed buildings, etc.), *recessing* (*e.g.*, jamb stones) and for sinking mouldings of cornices, etc. The maximum vertical movement is 3-ft. The area of sawn surface of Portland stone when the cut is 3-ft. deep and both blades are operating is approximately 800-sq. in. per min. This machine has largely replaced the single blade type.

Cross-cut or Beam Saw.—This consists of a long *transverse* cast iron beam, supported by a pillar at each end, along which a circular saw blade is caused to travel; it is obtainable in two sizes, allowing a maximum traverse of blade of 8 and 12-ft. The largest size of blade is 5-ft. and this gives a maximum depth of cut of approximately 25-in. A wide table, mounted on wheels or moving on inverted vee-slides (as shown at J), is usually provided, although side-by-side twin tables are also available.

The table, with the stone in position, is brought under the blade, adjusted and locked; the blade is then made to traverse and cut the stone. Both *fixed height* and *rise and fall movement* types are available, the former being useful for plain sawing and jointing (such as squaring ends of blocks of stone, edges of marble slabs, etc.) and the latter, which permits of a maximum vertical movement of the blade of 15-in., is invaluable for checking, channelling and recessing.

The blade may be of either the diamond or carborundum (see below) type. A typical cutting speed by a diamond saw is 220-sq. in. per min. for Portland stone; this speed is reduced to from one-third to one-half if the blade is of the carborundum type.

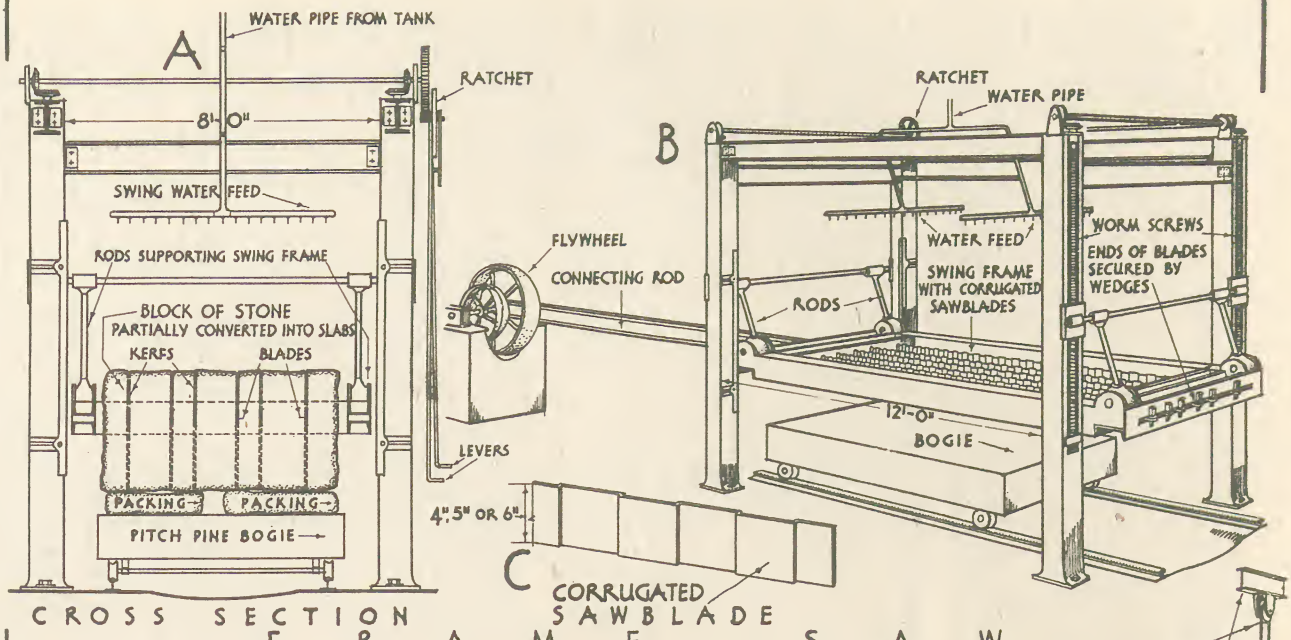
Gravity Saw (see F).—This type is so called as the table supporting the stone is pulled forward partly by the force of gravity. A counter-weight, adjusted according to the weight of the stone, is suspended by a wire rope which passes over pulley "1" (the block of which is secured to a roof, etc., beam), under the lower pulley "2," and is attached to the forward end of the moving table. Thus, a smooth pull, with a distinct economy in power, is obtained throughout the cut. The backward movement of the table is accomplished by operating the handwheel "1."

The cast iron table has transverse and longitudinal slots to receive clamps for the accurate setting and expeditious fastening down of the stone; it has a deep longitudinal slot to allow the blade to pass below the under surface of the stone. One type, of maximum size 120-in. by 39-in., is known as a *cross traverse table*, as it can be given a transverse movement by operating the handle of screw "2." The maximum cross movement is 30-in. A number of parallel cuts can thus be formed with one placing of the stone. The other type, called a *plain table*, cannot be moved transversely.

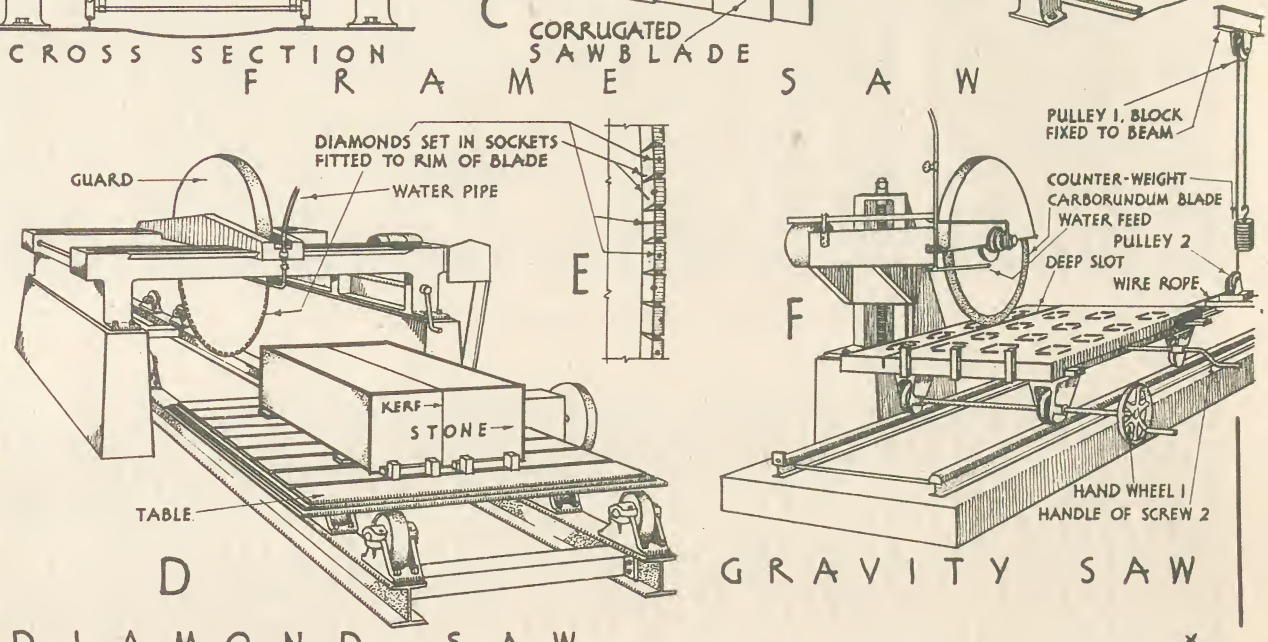
This machine may be provided with either a diamond blade or a *carborundum blade*. The latter is a steel blade with a 2 to 3-in. wide rim of carborundum (an abrasive material, being a crystalline compound of carbon and silicon); the carborundum, mixed with shellac, is heated and pressed round the periphery of the steel blade, which is dovetailed to provide a key. Carborundum blades give better finished surfaces and finer cuts than those formed by diamond blades, and they can be used for both hard and soft stones. Their cutting speeds are, however, not more than half those of diamond blades; thus, typical speeds are 8-in. per min. for 6-in. slabs of Portland stone and 4-in. per min. for 12-in. slabs, and these rates are approximately doubled if diamond blades are used.

Gravity saws are made of three types, namely, (1) *fixed height*, suitable for plain sawing and jointing, (2) *rise and fall* for checking, channelling and sinking, and (3) *universal*, which cuts the stone at any angle from vertical to horizontal, as it has a swivelling head which can be adjusted to a vertical or inclined plane as required. The latter can be provided with a carborundum wheel (16-in. diameter and from 1 to 2-in. thick) in lieu of the circular blade, which rotates in a vertical spindle and grinds and moulds the edges of the stone or marble.

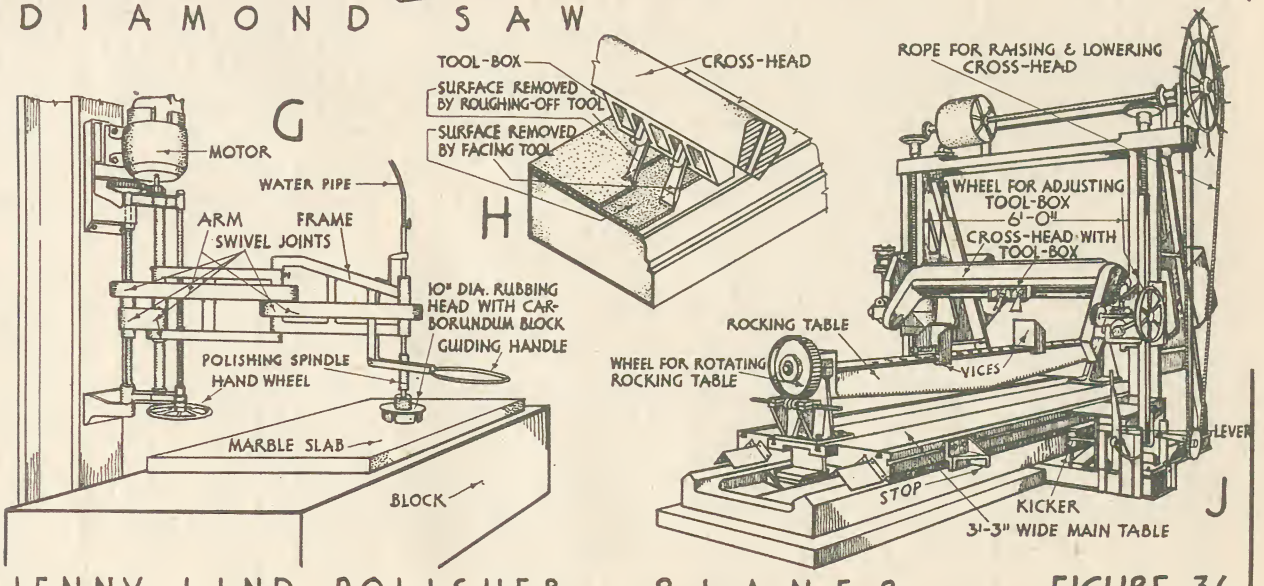
MASONRY MACHINES



CROSS SECTION FRAME SAW



DIAMOND SAW GRAVITY SAW



JENNY LIND POLISHER PLANER

FIGURE 36

PLANING AND MOULDING MACHINES.—As implied, these are used for machining the exposed face or faces to the desired finish and for moulding blocks of stone. One of the simplest, known as the *canting arm* or *reversible planer*, is shown at J. For surfacing, the stone (of a maximum length of 9-ft.) is fixed upon the *rocking table* between the two vices, with the face to be dressed uppermost. Wide blocks of stone fixed on the rocking table (which may be only 6½-in. wide) are accommodated by supporting the overhanging portions by wood struts resting upon wedges on the main table. One or more tools are fixed by wedges in the *tool box* and the latter is moved along the *cross-head* to the required position by manipulating the handwheel shown ; the cross-head is lowered by power or by the operator pulling down on the rope until the edge of the tool is just below the surface of the stone. As the main table which supports the loaded rocking table moves forward on inverted vee-slides, the surface of the stone is cut as indicated at H ; the cross-head (or *canting arm* or *reversible head*) swings over on the return travel of the stone which automatically occurs when the *stop*, adjusted as required at the side of the main table, comes in contact with the *kicker* which moves the driving belt from one pulley to the other. It thus cuts in both directions, and for this reason is recognized to be the best machine for surfacing.

The cross-head is lowered as required after each cut. The rate of surfacing stone is dependent upon several conditions, but an approximate average speed is 10-sq. ft. per min.

Whilst essentially used for surfacing, this machine can also be used for moulded work. Thus, for cornices and similar members, a *plate box* into which is fitted a plate or tool having an edge smithed to the reverse of the required mould is fixed in the tool box. The rocking table is rotated and fixed at the desired angle so as to bring the surface of the stone to be moulded into a convenient position relative to the tool which cuts the stone during the forward movement of the table. Before a stone is placed on the machine for moulding, one end is " cut in " to the required section by hand by the mason.

The rocking table can be removed so that large blocks can be machined by fixing them directly on to the main table.

For circular work, such as column " turning," two metal brackets are fixed to the main table. The block of stone is supported by two horizontal metal " centres " which are attached to the brackets and are let into the ends of the stone. The cutting process is as described above, the main table moving forward towards the tool box fixed in the middle of the cross-head and the stone rotated after each cut by means of gearing fixed on one side of the brackets. Flutes are formed, after the turning has been completed, by specially shaped tools fixed in the tool box. A column shaft up to 8-ft. long and 4-ft. 6-in. diameter can be worked on this machine.

Circular column shafts, caps and bases, balusters, etc., are also turned in a *lathe*. Like the wood-working lathe described on p. 30, Vol. III, the stone is fixed to two centres, and as it rotates it is cut by a tool fitted in a holder which traverses the length of the stone. Flutes are formed by the planing machine or by hand.

Other machines cut the stone in the forward direction only, and are known as *rigid head planing machines*. They have a quick return. They are especially invaluable for forming intricate moulded work. No hand finishing is necessary, as the machined-cut surfaces are excellent.

One of these rigid head planing machines, called an *open-side planer*, has two tool boxes, one within the cross-head (or cross-arm) and the other at the side of the single pillar. The upper tool box traverses the cross-arm and the tools can be made to move vertically ; the side tool box has a rise and fall motion and the horizontally fitted tools can be moved horizontally. The top tools cut the upper surface of the stone whilst the side tools mould the vertical surface at the same operation. A big saving of time thereby results. This machine is particularly effective for deep cornices. Unlike the canting-arm planer (see J), it has only one pillar and it can therefore deal with wide (up to 7-ft.) blocks ; it is employed for forming return mouldings on stones such as quoin cornices and string courses, square pillar and pilaster bases and caps, etc.

Another rigid head planing machine is the *four-head planer*. As implied, this has four tool boxes, *i.e.*, two in the cross-head and one at the side of each of the two pillars. Like those in the open-side planer, these tool boxes are independently operated, and the machine is therefore capable of moulding and surfacing the top and side faces of two blocks of stone at the same time.

For marble, granite and similar brittle stone, carborundum wheels of the required shape may be fitted into the tool boxes in lieu of steel tools. The abrasive action of these wheels, assisted by water delivered on the stone, forms the desired section as they rotate at a high speed.

POLISHING MACHINES.—These include the (*a*) Rubbing Bed, (*b*) Jenny Lind Polisher and (*c*) Disc Polisher.

(a) *Rubbing Bed.*—This consists of a circular metal table, 6 to 14-ft. diameter and 2 to 2½-in. thick, which revolves on a vertical spindle at a speed varying from 20 (the largest size) to 45 revs. per min. It has a circular trough round the rim to carry away the liquid slurry produced during the rubbing operation.

This machine is now used chiefly in marble and granite works, and whilst it was formerly employed for surfacing limestone and sandstone blocks, it is now rarely used for this purpose, as the circular saw—especially the carborundum saw—and planers give a surface which is satisfactory for most purposes at a cheaper cost.

The block or slab of marble, etc., is placed on the table, and sharp sand or steel shot, together with water, is applied as the table rotates. The friction created by the action of the abrasive between the table top and the stone produces a smooth surface. Large blocks are kept in position by a wood beam fixed across and slightly above the table. Small blocks are controlled by hand.

(b) *Jenny Lind Polisher.*—One of several types, known as the *rise and fall* model, is shown at G. It is used for smoothing and polishing flat surfaces of marble and granite blocks or slabs. The machine, which is fixed to a pillar or wall, consists of a metal frame carrying an arm and a vertical rotating *polishing spindle* to which is connected a *rubbing head* or a *polishing disc* ; the diameter of the head is 10-in. and that of the disc is 12-in. ; the discs of larger machines are up to 30-in. diameter. As shown, the frame with arm is in two sections and the swivel joints allow the head or disc to be easily guided in any direction ; each section of the arm is 3-ft. long and a 9-ft. by 4-ft. slab can be covered by the head at one fixing. The frame has a 2-ft. vertical adjustment by means of the hand wheel and screw and, in addition, the polishing spindle can be vertically adjusted through 7 or 8-in. The rubbing head revolves at a speed of 250 revs. per min. ; some machines have two speeds, one for smoothing and a quicker one for polishing.

A smooth surface is imparted to the marble or stone by carborundum blocks, which are of four grades, *i.e.*, coarse, medium, fine and finishing. These are fixed in turn in this order to the rubbing head ; the abrasive action of these blocks as they rotate, together with the water which is delivered through the hollow polishing spindle, gives the smooth surface. This is followed by the final polishing process, the fine carborundum block being replaced by the *polishing disc*, which is a metal plate faced with felt ; oxide of tin, known as *putty powder*, is applied, in addition to water ; the rotary action gradually imparts a high polish to the stone.

A marble slab, after being sawn, is smoothed and polished (or " glossed ") in the following manner : The slab is set on the stone bench, the coarse carborundum block is fitted to the rubbing head and the spindle is adjusted to the required height. The motor is started, the water is turned on and the operator, holding the guiding handle, gradually directs the rotating block over the whole surface. The pressure of the carborundum block is increased or diminished by the operator lowering or raising the handle. When the surface has been rubbed down to an even surface, the coarse carborundum block is replaced by the medium block and the process is repeated. After the fine and finishing blocks have been applied in a similar manner, the surface should be very smooth. Any grit on the marble must now be removed, the polishing disc is fixed, putty powder is sprinkled over the slab, and the surface is traversed as described until a high polish is obtained.

A splash-board, not shown in the sketch, is used to protect the operator from the slurry ; it is fitted to the bench between the slab and the operator and with its upper edge about 6-in. above the top of the slab.

Slabs longer than 9-ft. must be re-set on the bench to allow the untreated surface to be dealt with. This is obviated if, instead of the fixed bench, a bogie—which runs on a track—is available.

A *fixed-height* model of this machine, cheaper than the one described, has no rise and fall main adjustment, but the polishing spindle has a 7-in. vertical movement.

(c) *Disc Polisher*.—This has a long vertical rotary spindle attached at its upper end by a universal joint to the motor above and with a 15-in. diameter disc at its lower end. The spindle is telescopic to allow for the adjustment of the disc at the required height, and the universal joint permits an area of approximately 7-ft. diameter of marble or granite to be polished.

Moulded surfaces of marble cannot be smoothed and polished by these machines and are dealt with by hand. Such work is smoothed or " grounded " by using different grades of carborundum powder; a piece of *snake stone* (Water of Ayr stone) is then applied to complete the smoothing process, after which the surface is polished by applying putty powder on a felt " jack " or pad.

Granite surfaces, especially when they have been axed (see below), are sometimes smoothed by the application of steel shot and emery powder instead of the carborundum blocks. During the first or *shotting* process, the rough surface is rendered perfectly flat by the abrasive action of the shot and water and the rotary cast steel plate of the Jenny Lind Polisher head. The second process is called *emerying*, as emery is used in lieu of shot; this completes the grinding operation. All traces of the emery are removed, and the glossing or polishing operation is performed with the felted disc and putty powder. Sometimes oil is rubbed into the granite to give a rich gloss.

Instead of hand grinding and polishing moulded granite surfaces, these operations may be performed by a *pendulum* or *slider*. A metal casting of the reverse shape of the required granite section is made and attached to one end of a long rod which is connected at the opposite end to a vertical member which is caused to swing sideways like a pendulum. After the casting has been correctly placed on the moulded granite, it is caused to swing to and fro as the pendulum swings; shot, emery, putty powder and water are applied in turn during the process.

Pneumatic Dressing and Carving Plant.—This comprises an air compressor, air receiver, cast iron main air pipe, flexible branch air pipes or hoses, pneumatic hammers and chisels. The latter tools include the punch or puncheon, plain, broad or flat, tooth (having serrated edges) and bush chisels; the bush chisel consists of several steel blades, having sharpened edges, bolted together, and is used for dressing the roughest blocks. The tools are fitted into the pneumatic hammers and the latter are attached to the flexible air hoses; a cock is fitted near the end of each hose by which the compressed air can be turned on or off by the operator. When the air is admitted to the hammer, the piston within the latter strikes in rapid succession the head of the shank of the tool; the effect of this percussion action is therefore similar to that obtained by the mason when he strikes a chisel with a mallet. Hence the dressing operation is comparatively simple, as the operator is only required to turn on the air, place the tool on the surface of the stone and guide it in the required direction. These tools are very rapid in action and are capable of doing work ranging from the heaviest dressing to elaborate carving. They are especially effective for dressing intractable stone, such as granite and certain marble. The size of the plant varies, the largest being capable of operating fifteen hammers and employing the same number of masons.

Pneumatic hammers and machinery, such as the frame and carborundum saws, have largely superseded hand-dressing of granite.

Where the latter is still employed, the operations are somewhat similar to those described on pp. 35-38, Vol. I. The scappling hammer or pick is used for hammer-faced and picked work; fine picked work is produced by a fine-pointed pick or a hammer having a serrated edge; punched work is obtained by a punch or puncheon which, unlike that shown at N, Fig. 19, Vol. I, is in the form of a hammer resembling a blunt pick. Single axed work is done with an axe or hexagonal headed hammer after the surface has been picked; this produces parallel lines on the surface which are barely visible in fine axed work. The finest surface given to a block of granite before being smoothed and polished is produced by a hammer called a *patent axe* after the face has been dressed with the ordinary axe; the head of the patent axe consists of sharp steel blades, one end of the head has a larger number and finer blades than the other and is used after the end with the thicker blades has been employed.

Helicoidal Wire Sawing Plant.—This is used for quarrying stone and for reducing large blocks to a size suitable for the frame saw. It consists of a long wire (of $\frac{5}{16}$ to $\frac{1}{4}$-in. diameter) which travels over and under several pulleys at a rate of approximately 200-ft. per min. as it produces a vertical cut in the stone. The system has not been commonly adopted in this country.

STONE DRESSINGS TO OPENINGS

Examples of dressings to openings additional to those illustrated in Vol. I are shown in Figs. 37-42 inclusive.

Six elevations of entrances are shown in Fig. 37. The same treatment may also be applied to window openings. Those at A, B, C, D and E show semi-circular arches, and that at F is segmental. All of the arches have stepped extradoses.

The voussoirs forming the semicircular arch at A have ears or crossettes. The keystone extends to a string course. A satisfactory proportion of opening is obtained if the 60° diagonal intersects the top of the transome, as shown (see also C). The ashlar consists of alternate thin and thicker courses, that on the left having rusticated joints (such as the channelled joint at A, Fig. 41) and that on the right being flush-jointed.

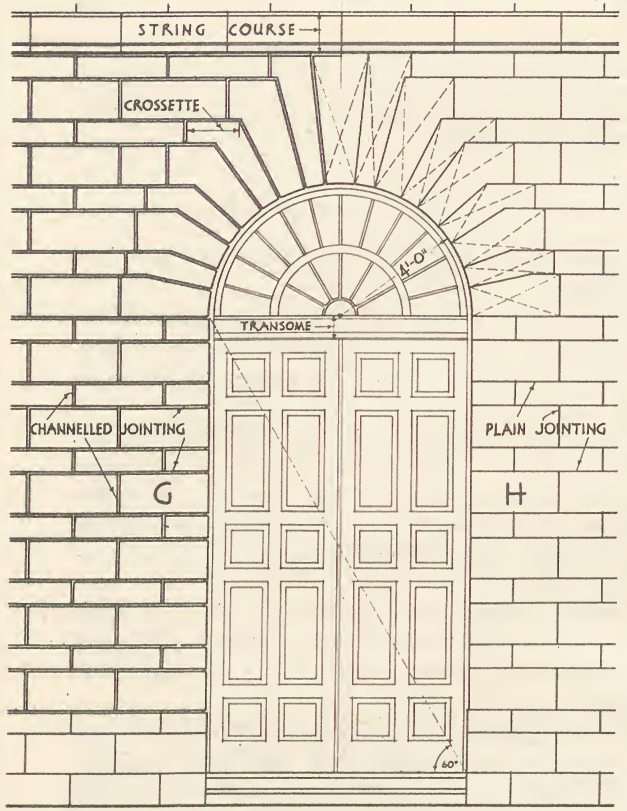
In all of the examples, broken diagonal lines indicate the size and shape of each voussoir, etc. Ambiguity is thus removed and the bonding is made clear. A working drawing should also have the amount of bed of each stone specified by ringed figures (see Fig. 24, Vol. I).

The treatment at B gives a bold appearance which is particularly effective for large openings. Plain courses alternate with those consisting of blocks having a large projection. The latter, detailed at S, shows a rock-faced middle portion of each block which is emphasized by the contrasting smooth or plain finished mouldings. With certain exceptions, the joints are channelled; the exceptions include the plain vertical joints necessary to limit the size of some of the voussoirs. The courses above the springing are wider than those below, and a moulded course at the impost, such as is shown on the left, may be preferred to separate the two. The broken construction lines show that the channelled joints and cyma mouldings of the voussoirs are parallel, and thus the rusticated portions are tapered.

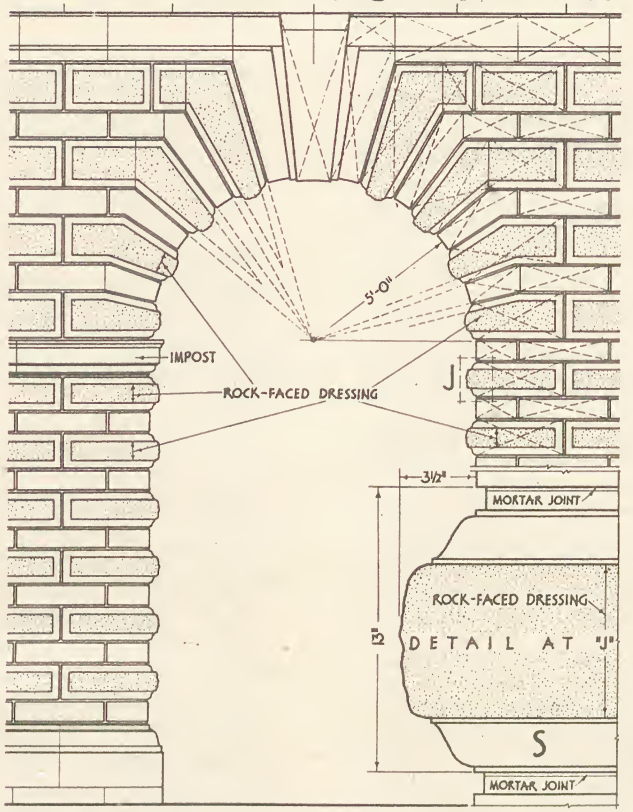
The opening at C shows a recessed jamb (see plan K). The arch is similarly recessed and consists of two rings—note the value of the broken diagonal lines as indicating this. The voussoirs of the outer ring is moulded as shown at M. The bold appearance is here shown of the steps detailed in section at M, Fig. 45.

Another example of a two-ringed arch is shown at D. This differs from C in that the inner ring is moulded (see O) and the bed joints of its voussoirs coincide with alternate bed joints of the outer ring voussoirs. The voussoirs course with the ashlar shown on the left. For brick walls the voussoirs should course with the brickwork as shown on the right.

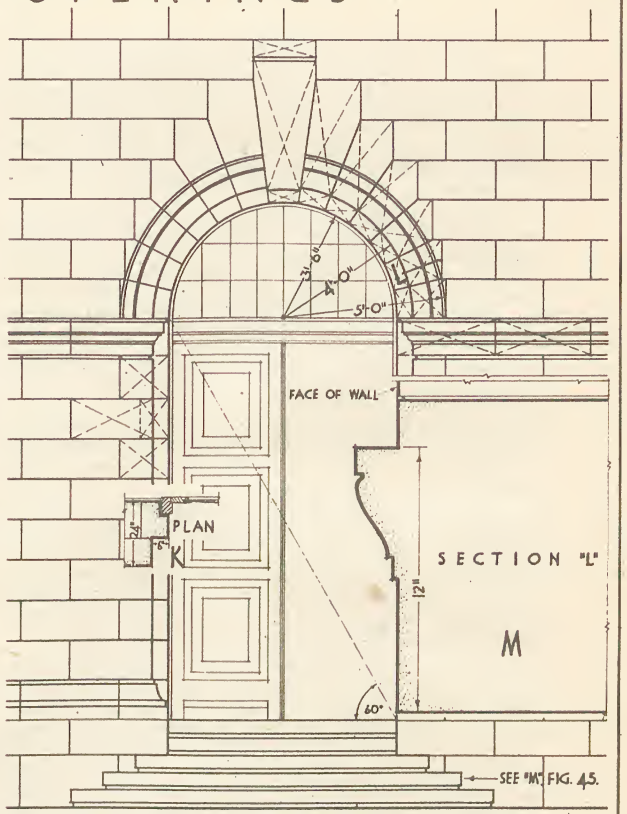
STONE DRESSINGS TO DOOR OPENINGS



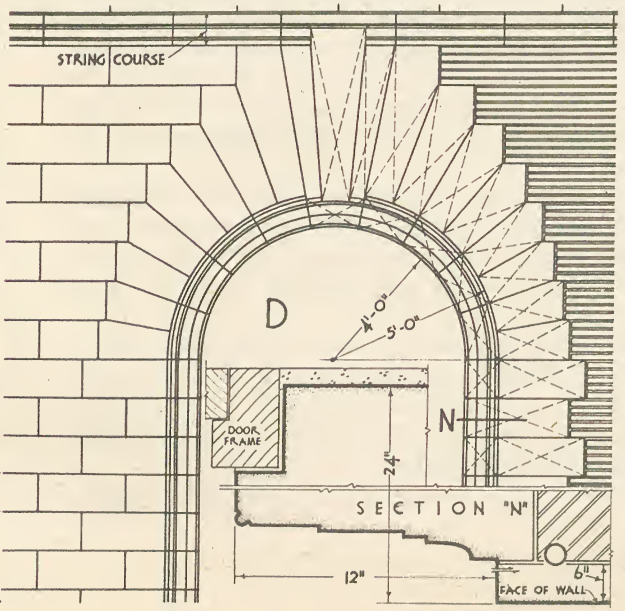
A

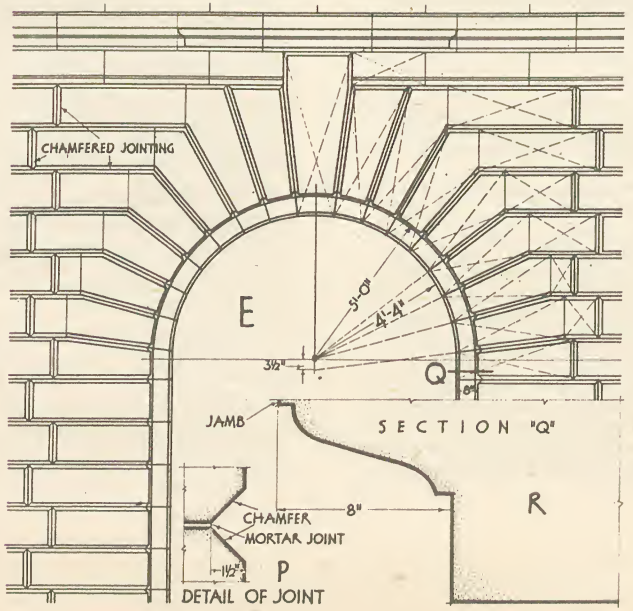


B



C





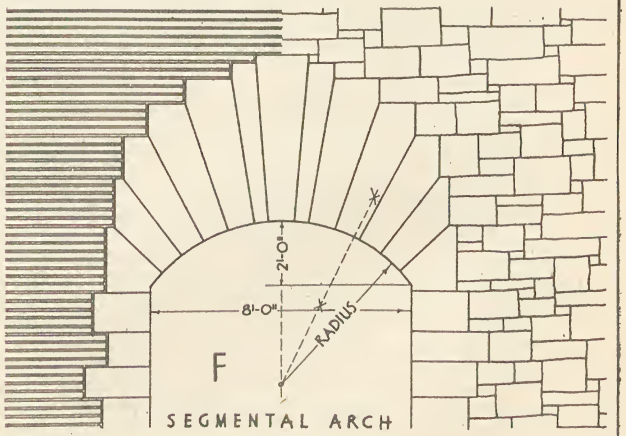
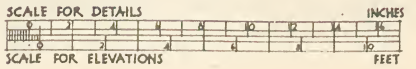


FIGURE 37

The arch at E differs from the two preceding examples, as it is only a single-ringed arch, each voussoir being moulded as shown at R. The general jointing is chamfered (see P) and the vertical joints of the voussoirs may be also chamfered as an alternative to the plain joints shown.

The application of a stepped extradosed arch to a segmental headed opening is shown at F; the voussoirs are shown coursing with brickwork on the left and, as an alternative, with squared rubble walling on the right. The bed joint of the lower voussoir or springer is below the springing line; this is necessary in order that the springer may be of satisfactory proportions.

Each of the openings shown in Fig. 37 may accommodate a pair of folding doors and a transome light, such as are faintly indicated at A and C.

Examples of six square-headed door openings are illustrated in Fig. 38. Enlarged details of this stonework are shown in Fig. 39.

The height of a classic door opening is at least twice its width, but this proportion is not habitually followed. The example at B and C, Fig. 38, is in accordance with tradition, whilst E and H show the height to be 4-ft. greater than the width, a proportion which conforms to that of most of the standard internal doors listed on p. 87, Vol. I.

The doorway shown in elevation at A, Fig. 38, suitable for a house, is provided with an entablature. The latter consists of a moulded architrave, frieze and cornice. The student is recommended to study a classic entablature, such as that shown at A and B, Fig. 43, in order to become conversant with the proportions of the traditional type. Whilst these general proportions are often departed from in current practice, such divergence should be strictly limited. Two alternative details of this entablature are shown at A and B, Fig. 39. That at A conforms most closely to the elevation; because of the cushion-shaped appearance of the frieze, which is said to be *pulvinated*, the centre of the arc forming the pulvination is obtained as shown at L, Fig. 41. A flat frieze is shown at B, Fig. 39; whilst this is of the same height as that at A, it is usual to make a pulvinated frieze three-quarters of the height of the architrave and a plain frieze equal to the architrave. In accordance with tradition, the width of an architrave is about one-sixth the width of the opening, and the cornice is from one and a quarter to one and a third the height of the architrave. Thus, the classical proportions of this doorway would be as follows: Architrave, $\frac{1}{6} \times 3$-ft. 6-in. $= 7$-in. wide; frieze, $\frac{3}{4} \times 7$-in. $= 5\frac{1}{4}$-in. high (if pulvinated) and 7-in. (if plain); and cornice, $\frac{5}{4}$ to $\frac{4}{3} \times 7$-in. or about 9-in. (see also G, Fig. 40, and L and M, Fig. 41).

The elevation at A shows ashlar walling on the left and brickwork as an alternative on the right. The moulded jambs may be coursed as shown on the left, or the number of bed joints in the architrave may be reduced as indicated on the right; a bond stone in the architrave, shown by broken lines at S, may be used, or a good bond may be obtained if alternate jamb stones are shaped as shown by full lines at D, Fig. 44. In order to minimize awkward cutting of the brickwork at the cornice, the latter may be finished square as shown by broken lines at T.

A pedimented doorway [1] is shown in elevation at C and in section at B, Fig. 38. A pediment is a triangular feature which crowns a doorway, window, gable, etc.; its lower boundary being the horizontal corona and bedmould, and its sloping boundaries being the complete cornice; the triangular space between these horizontal and raking members is occupied by one or several stones and is called the *tympanum* or core. A modification of this triangular pediment is the segmental pediment, the cornice being curved to the shape of a segment.

The pediment is often made excessively high. This is avoided, and a satisfactory proportion obtained, if the geometrical construction shown at C is adhered to. Thus, with one end "*a*" of the fillet of the corona as centre and its whole length "*ab*" as radius, an arc is drawn to intersect the centre line at "*c*"; with "*c*" as centre and "*cb*" as radius an arc is struck intersecting the centre line at "*d*"; the latter should be the point of intersection of either the bottom of the raking corona as shown or the bottom of the raking bedmould.

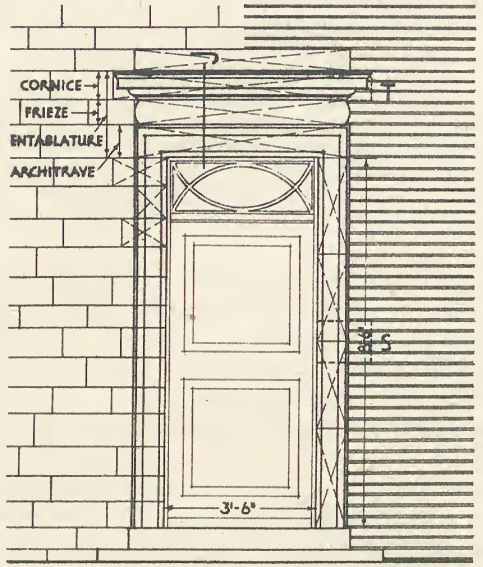
It will be observed that the raking cornice consists of the crown mould comprising a cyma recta with fillet, the corona and bedmould. This is shown more clearly in the enlarged detail at C, Fig. 39, where P equals Q. The jointing of the stonework should be carefully studied. The lower end stone or *springer* comprises portions of the cornice, the horizontal corona and bedmould; it courses with the adjacent ashlar, forming top and bottom horizontal bed joints, a vertical joint at the end of the cornice, and the fourth boundary consists of a vertical joint at the horizontal corona and bedmould which is continued as a normal joint at the raking cornice; this latter joint coincides with the intersection between the bottom of the raking bedmould and the fillet of the horizontal corona. The apex stone is also coursed in with the ashlar, the cornice being stopped against the wall face and the upper bed coinciding with the horizontal bed joint of the ashlar. A departure from the latter bed joint is usually made if the stone pediment occurs in a brick wall; here the projecting sloping surface of each stone of the cornice is continued to the back and the brickwork is cut to intersect this raking surface.

A detailed section through the architrave is shown at S, Fig. 39, and a portion of the elevation is shown at R. The stonework at the principal entrance of an important building may be enriched by carving. Many existing examples show very elaborate enrichment, but owing to the high cost of such work, the present tendency is to economize in this direction. Where such decoration is applied, it is usual to limit it to the bedmould, one or two members of the architrave and occasionally to the crown mould. An example of ornamentation is indicated at R. Care should be taken to provide adequate material in the member for the carver to produce the required ornament. Thus, the bead U at S, Fig. 39, formed by the moulding machine (J, Fig. 36), is suitable for the carving of the *bead and real* ornament shown at R; similarly, the ovolo bedmould is suited to receive the *egg and dart* ornament indicated in Fig. 42. An alternative to this architrave

[1] This type is usually deferred to the third year of a course, and the pediment is therefore elaborated in Vol. IV.

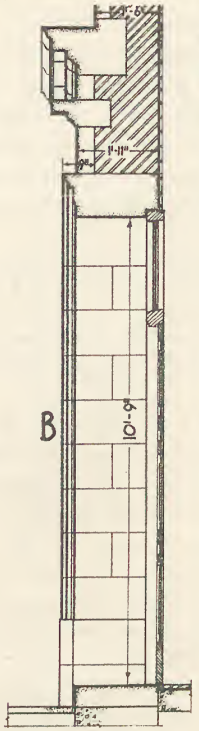
STONE DRESSINGS TO DOOR OPENINGS

NOTE: ENLARGED DETAILS OF THE STONE MOULDINGS ARE SHOWN IN FIG. 39.

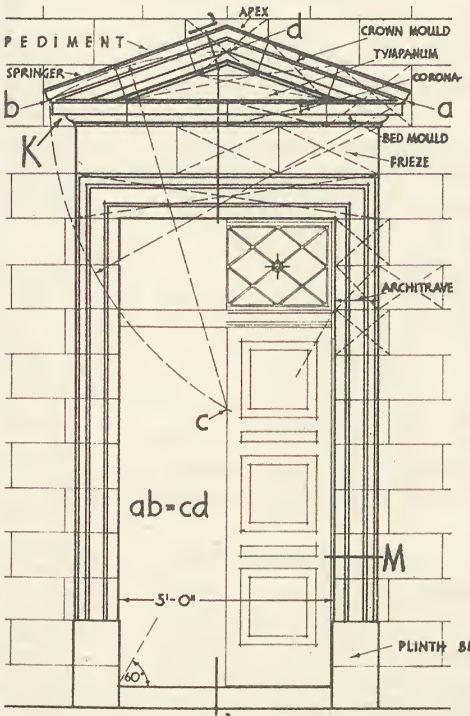


A

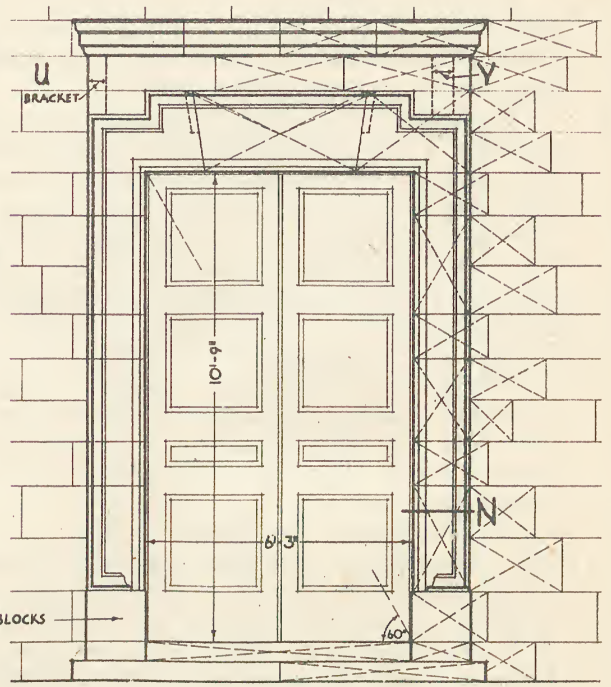
SEE FIG. 21, VOLUME 3.



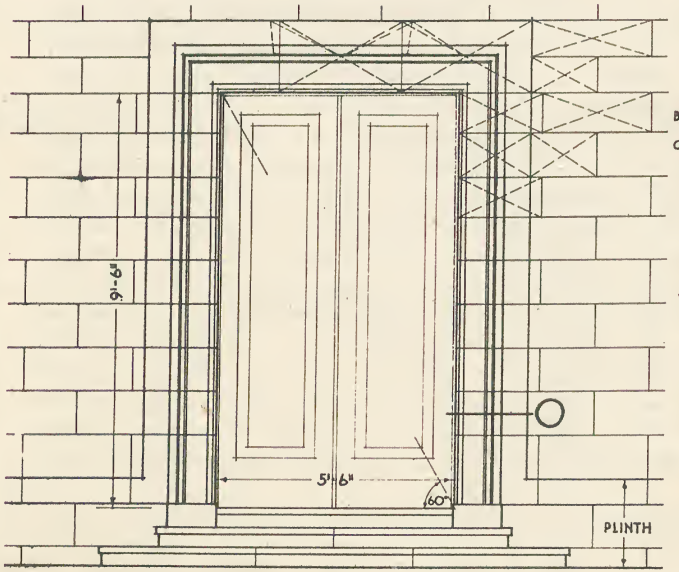
SECTION "L L"



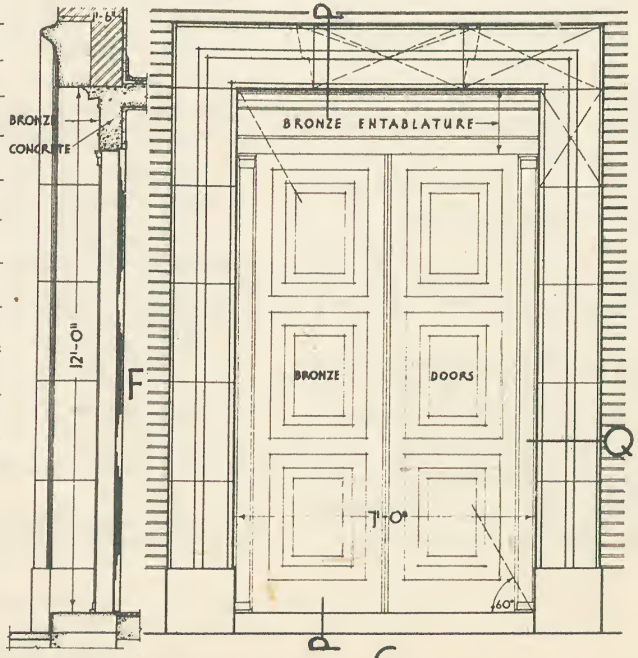
C



D

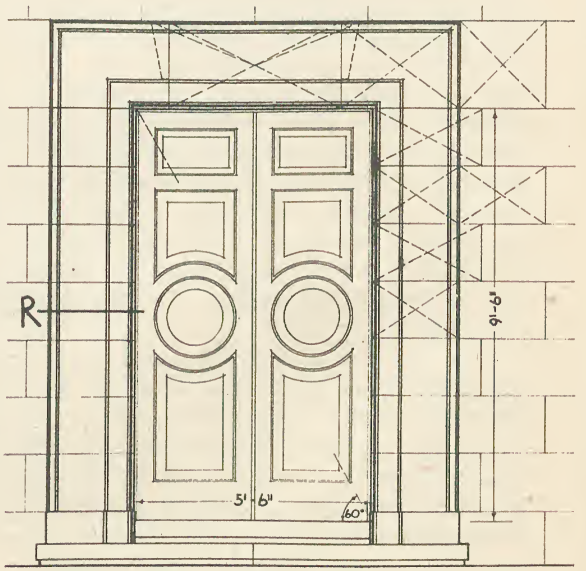


E



SECTION "P P"

G

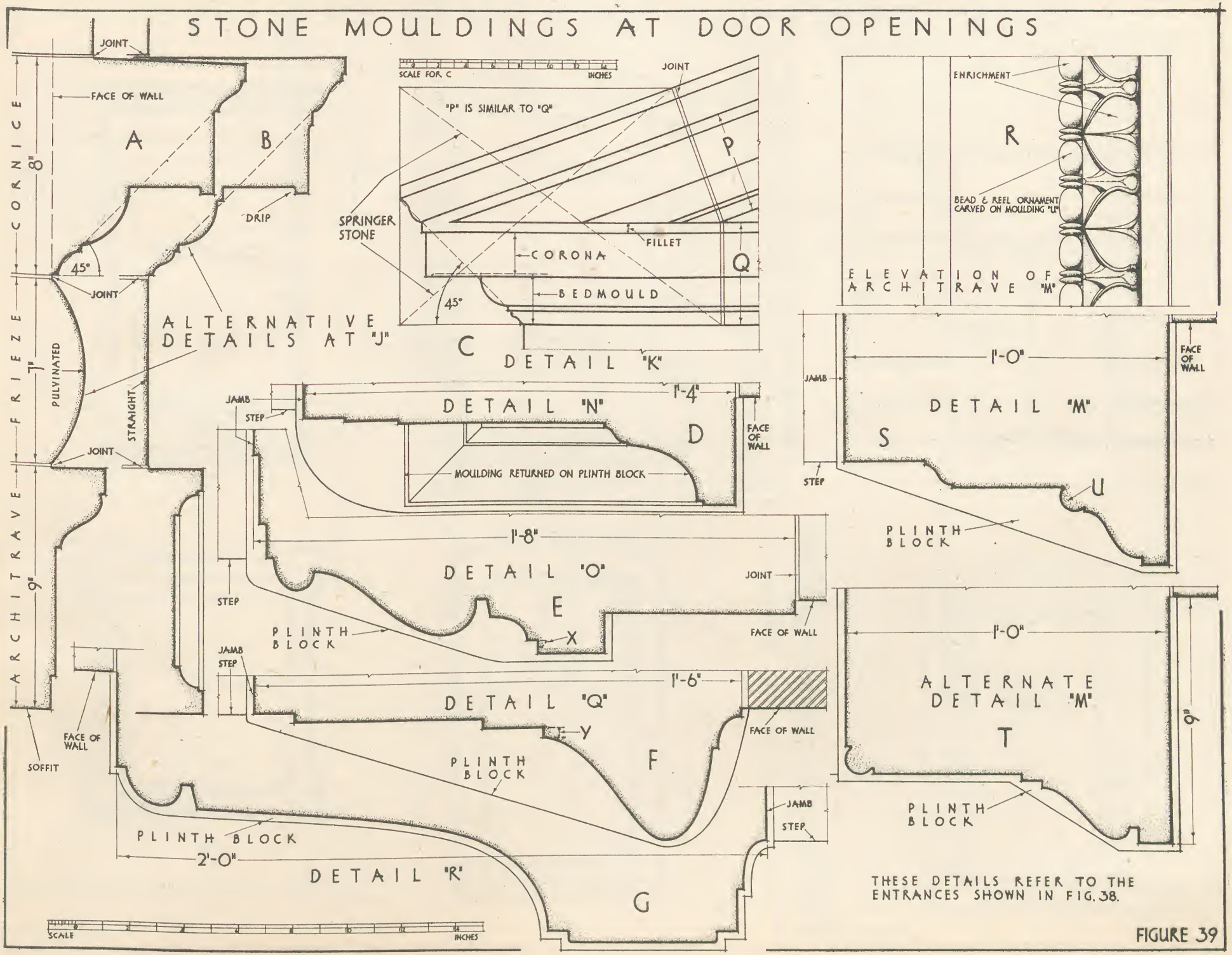


H

SCALE 0 2 4 6 8 10 12 FEET

FIGURE 38

STONE MOULDINGS AT DOOR OPENINGS

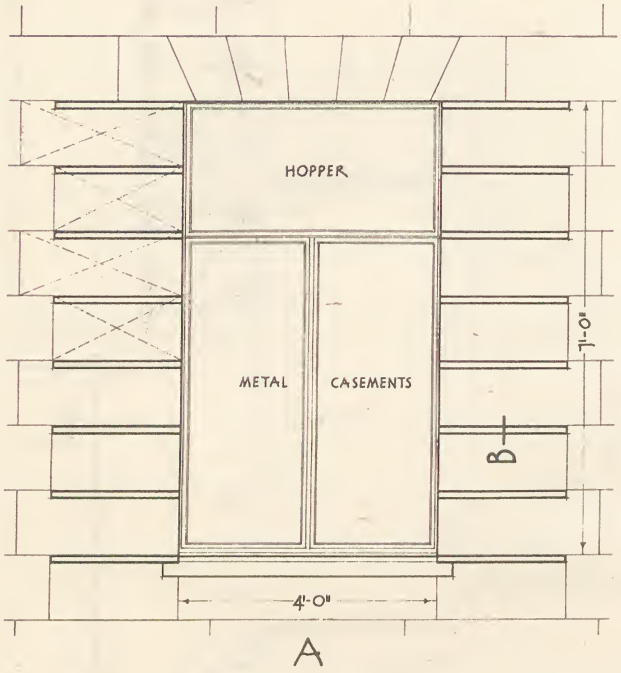


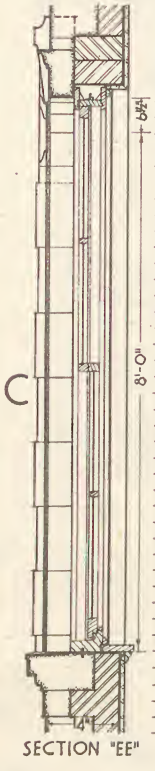
THESE DETAILS REFER TO THE ENTRANCES SHOWN IN FIG. 38.

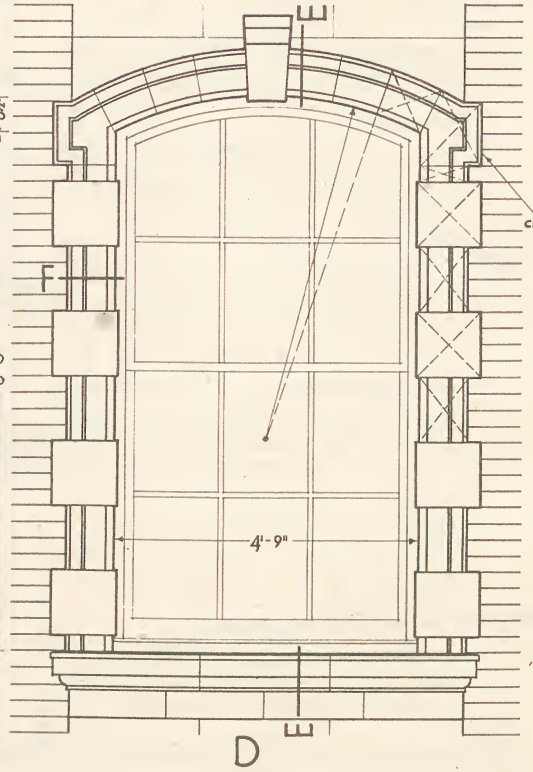
FIGURE 39

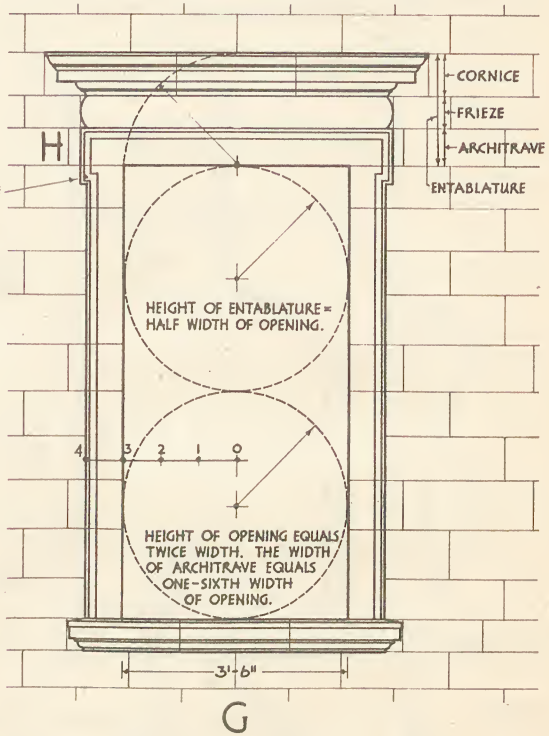
STONE DRESSINGS TO WINDOW OPENINGS

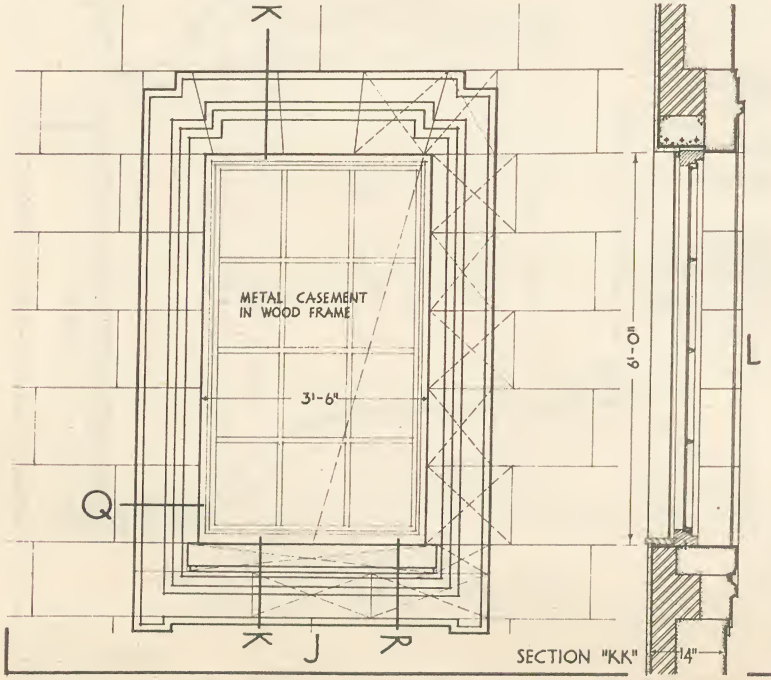
NOTE: ENLARGED DETAILS OF THE STONE MOULDINGS ARE SHOWN IN FIG. 41.

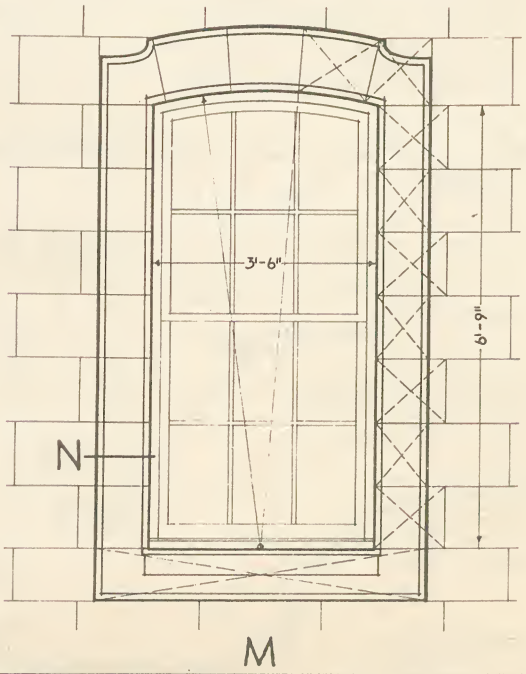












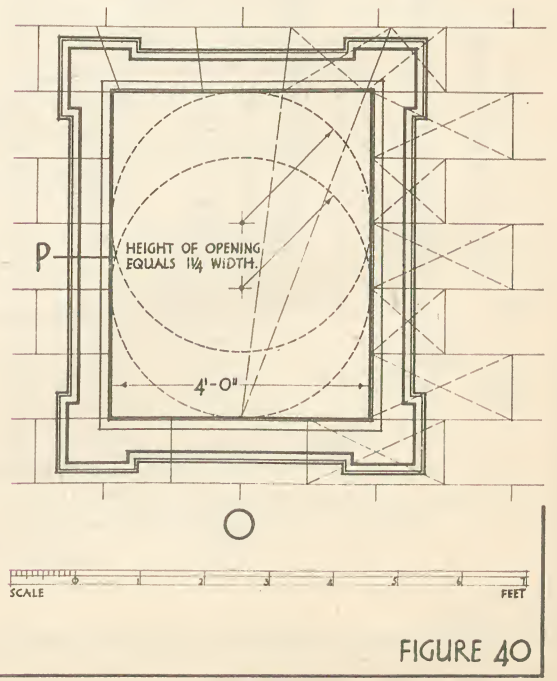
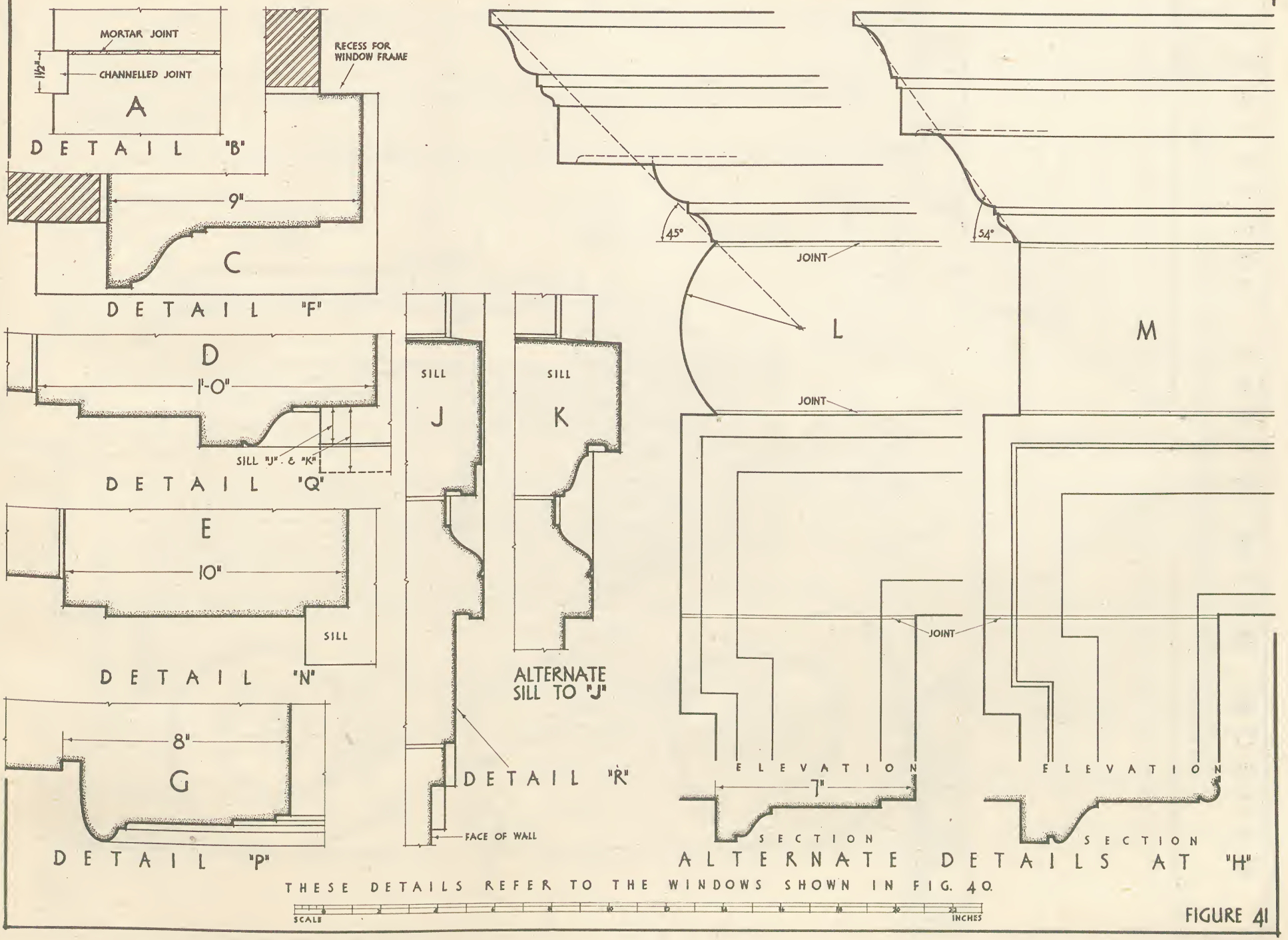


FIGURE 40

DETAILS OF MASONRY AT WINDOW OPENINGS



THESE DETAILS REFER TO THE WINDOWS SHOWN IN FIG. 40.

SCALE 0 2 4 6 8 10 12 14 16 18 20 22 INCHES

FIGURE 41

WINDOW WITH STONE DRESSINGS

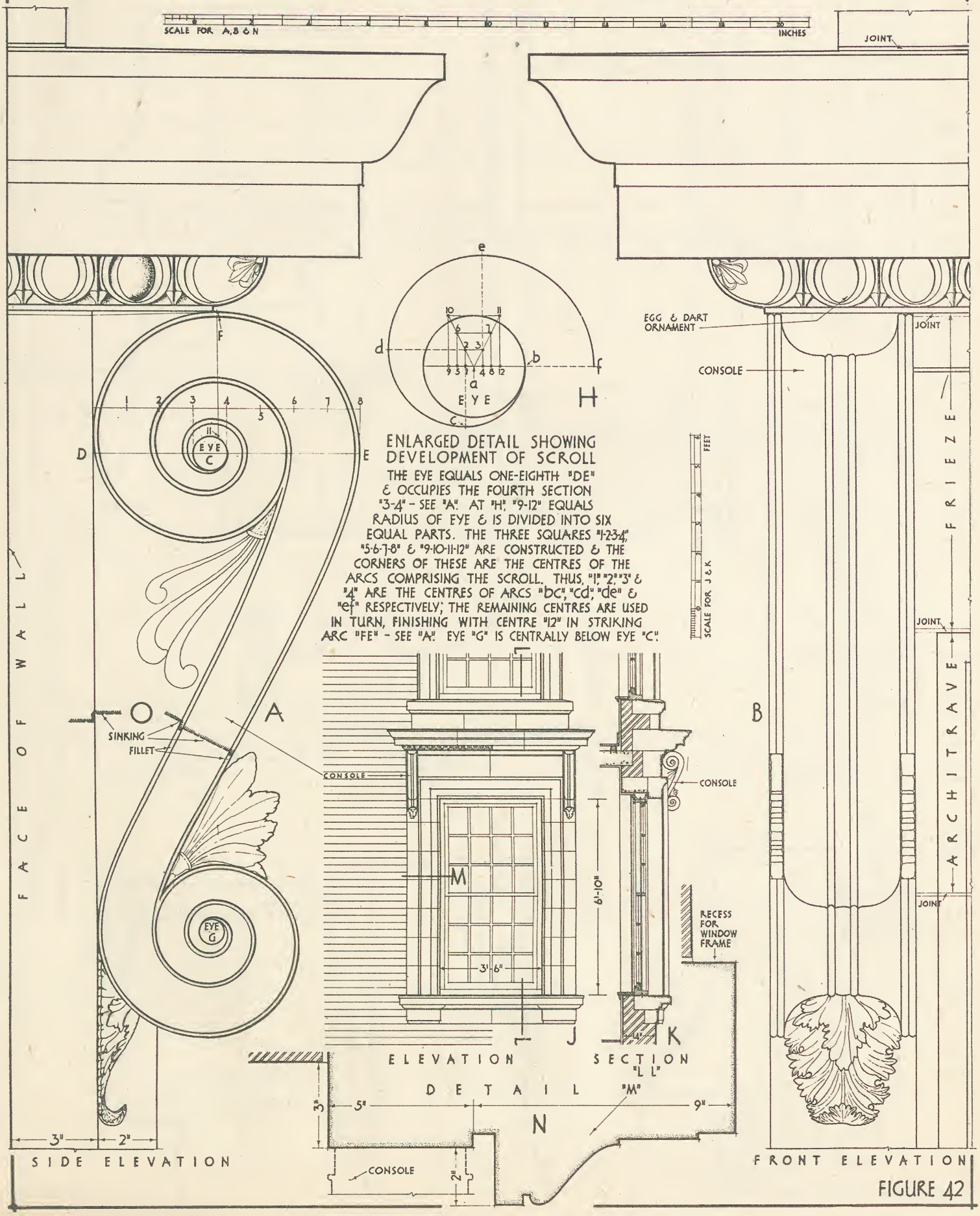

SCALE FOR A, B & N
INCHES
JOINT
EGG & DART ORNAMENT
CONSOLE
FRIEZE
ARCHITRAVE
JOINT
JOINT
JOINT
FACE OF WALL
SINKING
FILLET
CONSOLE
CONSOLE
RECESS FOR WINDOW FRAME
61-10"
3'-6"
14"
EYE C
EYE G
EYE
ENLARGED DETAIL SHOWING DEVELOPMENT OF SCROLL
THE EYE EQUALS ONE-EIGHTH "DE" & OCCUPIES THE FOURTH SECTION "3-4" - SEE "A". AT "H", "9-12" EQUALS RADIUS OF EYE & IS DIVIDED INTO SIX EQUAL PARTS. THE THREE SQUARES "1-2-3-4", "5-6-7-8" & "9-10-11-12" ARE CONSTRUCTED & THE CORNERS OF THESE ARE THE CENTRES OF THE ARCS COMPRISING THE SCROLL. THUS, "1", "2", "3" & "4" ARE THE CENTRES OF ARCS "bc", "cd", "de" & "ef" RESPECTIVELY; THE REMAINING CENTRES ARE USED IN TURN, FINISHING WITH CENTRE "12" IN STRIKING ARC "FE" - SEE "A". EYE "G" IS CENTRALLY BELOW EYE "C".
FEET
SCALE FOR J & K
ELEVATION
SECTION "L L"
DETAIL "M"
3"
5"
9"
2"
CONSOLE
SIDE ELEVATION
FRONT ELEVATION

FIGURE 42

is detailed at T, Fig. 39. Whilst some of the close grained sandstones can be finely carved, the limestone class is generally most suited for this purpose.

The architrave of the entrance D, Fig. 38, is detailed at D, Fig. 39. Note that its outer members are returned on the plinth block, which latter must, of course, have an adequate projection to receive it. The head of this architrave (like that at E, G and H, Fig. 38) is formed of three stones with secret joggle joints (see D, Fig. 25, Vol. I). An additional feature may be provided either at U or V in the form of brackets or *consoles* similar to, but much shorter than, that detailed in Fig. 42 and placed below an increased projecting cornice.

The entrance at E, Fig. 38, has a wide architrave which is detailed at E, Fig. 39. The broad outer flat band is continued to form the upper member of the plinth. The shadow produced at the deep sinking emphasizes the rather bold curved member.

The detail of the architrave at F and G, Fig. 38, is shown at F, Fig. 39. The prominent moulded member is effective, but see the note below regarding protection of projecting masonry. It will be observed that the stonework courses with the brickwork.

Principal doors of buildings of importance are frequently of bronze. The door, with pediment and entablature, shown at F and G is an example. Consideration of bronze details is deferred to the Advanced Course. Briefly, the bronze of the entablature and pilaster is of $\frac{1}{4}$-in. thick cast bronze, and, for best work, the external face of the door is formed with $\frac{1}{4}$-in. thick bronze cast in the form of panels, and an $\frac{1}{8}$-in. thick sheet bronze backing; the door is 2-in. thick, with a space between the facing and backing.

An example of a very wide architrave is shown at H, Fig. 38, and detailed at G, Fig. 39.

The necessary lead covering of cornices has been purposely omitted in order to make the stone details as clear as possible. It cannot be too strongly emphasized that all projecting stone members should be protected as shown in Fig. 74, Vol. I. This is especially necessary in smoke-laden districts (see p. 97). Thus, for example, in addition to the cornice shown at B and C, Fig. 38, the upper surface of the horizontal corona should be given a very slight weathering and be covered with lead. The value of the drip and throating should also be appreciated (see Fig. 43 and p. 115). The modern tendency of omitting projecting courses, such as cornices, string courses and sills—with their drips and throatings—has resulted in many recent buildings becoming horribly disfigured within a very short time after erection. Such disfigurement is very pronounced at door and window openings which have been finished simply with wide, plain but slightly projecting bands or fillets. Referring again to some of the entrances illustrated in Fig. 38 and detailed in Fig. 39, it is seen that certain of the details should be slightly modified unless protection by string courses, porticoes, etc., is afforded. Thus, for example, a small throat could with advantage be formed at E (see broken lines at X) and F (Y to be widened to allow for the small throat), Fig. 39.

Additional doorways are shown in Fig. 44, and, as already pointed out, these door dressings can also be applied to windows.

Six examples of the stone treatment at windows are illustrated in Fig. 40 and detailed in Fig. 41.

The opening at A, Fig. 40, accommodates a pair of metal casements (see Fig. 28, Vol. III) and a hopper light. The elongated channelled bed joints, detailed at A, Fig. 41, are an effective contrast to the adjacent plain jointing.

The double-hung sashed window shown at C and D, Fig. 40, has a stone segmental head backed with a two-ringed rough brick arch, and the architrave consists of alternate moulded and projecting plain blocks. This is detailed at C, Fig. 41.

The opening at G, Fig. 40, shows an entablature. Traditional proportions are indicated. Two alternative details are shown at L and M, Fig. 41.

The metal casement in a wood frame (see Fig. 28, Vol. III) shown at J and L, Fig. 40, is detailed at D, Fig. 41. The latter figure also shows two alternative details of the window sill at J and K.

The openings at M and O, Fig. 40, are detailed at E and G, Fig. 41.

An elevation and vertical section of a double-hung sashed window are shown at J and K, Fig. 42. The stone dressings include an entablature with consoles or brackets.[1] The latter are often elaborately enriched with carving and usually take the form of a *scroll* (resembling a partially unrolled scroll of parchment) or *volute*. Detail A shows the side view of a console and one of several methods of constructing a scroll is there shown and explained at H. The elevation is shown at B and the architrave is detailed at N. An application of consoles to an entrance is illustrated at H, Fig. 44.

CORNICES

Several cornices are illustrated in Fig. 43 as alternatives to those shown in Vol. I.

The plan and elevation of a classic (Corinthian) entablature are shown at A and B, Fig. 43. Many important modern buildings have been completed with entablatures of proportions which conform very closely to those indicated in this traditional example.[2] Students should study these proportions very closely and be guided by them when designing stonework for upper features of buildings and dressings at door and window openings.

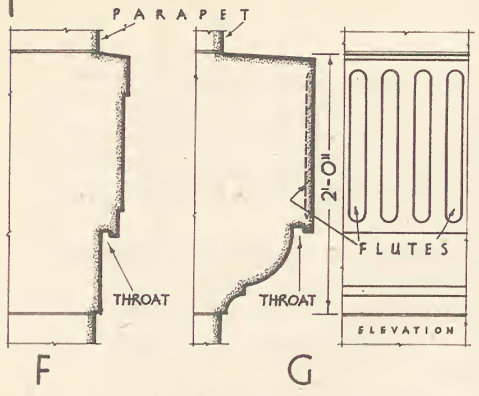
The cornice may be provided with a gutter as shown by broken lines at A, or be similar to that at N, or it may be weathered in the more usual manner as shown at L. The outlet from the gutter, such as a lead branch pipe, would be connected to a rain-water pipe fixed in an inconspicuous position; in order to avoid mutilation of the stonework, the outlet sometimes takes the form of a swan-neck bend connected to an internal rain-water pipe. Enrichment, in the form of a carved bedmould, cymatium (occasionally), modillions (in the form of horizontal scrolls) and sunk panels (often rose-shaped and therefore known as *roses*), may be provided.

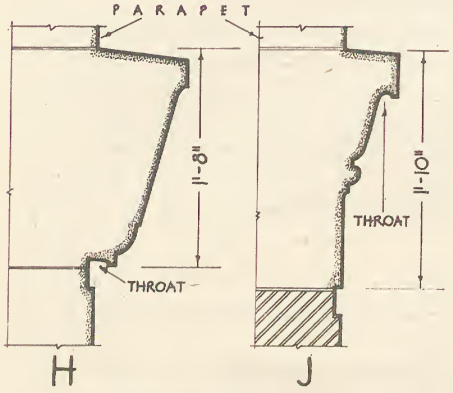
The sections at F, G, H and J show cornices having a small projection. They could also be used as string courses. The section and elevation at G show a

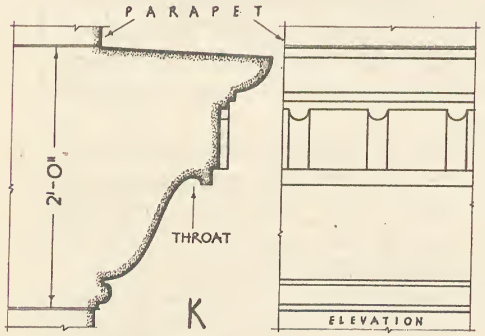
[1] These are further illustrated in Vol. IV.

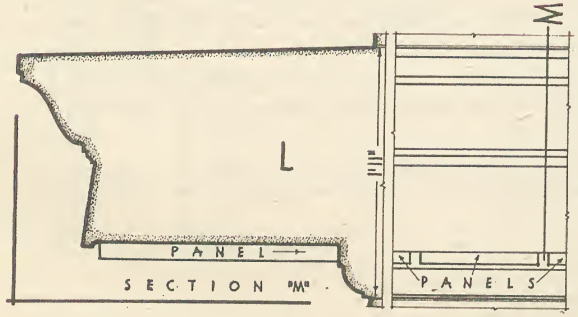
[2] The proportions of a classic entablature are based upon the diameter of a column just above its base. Details of an order, comprising columns, entablature, etc., are given in Vol. IV.

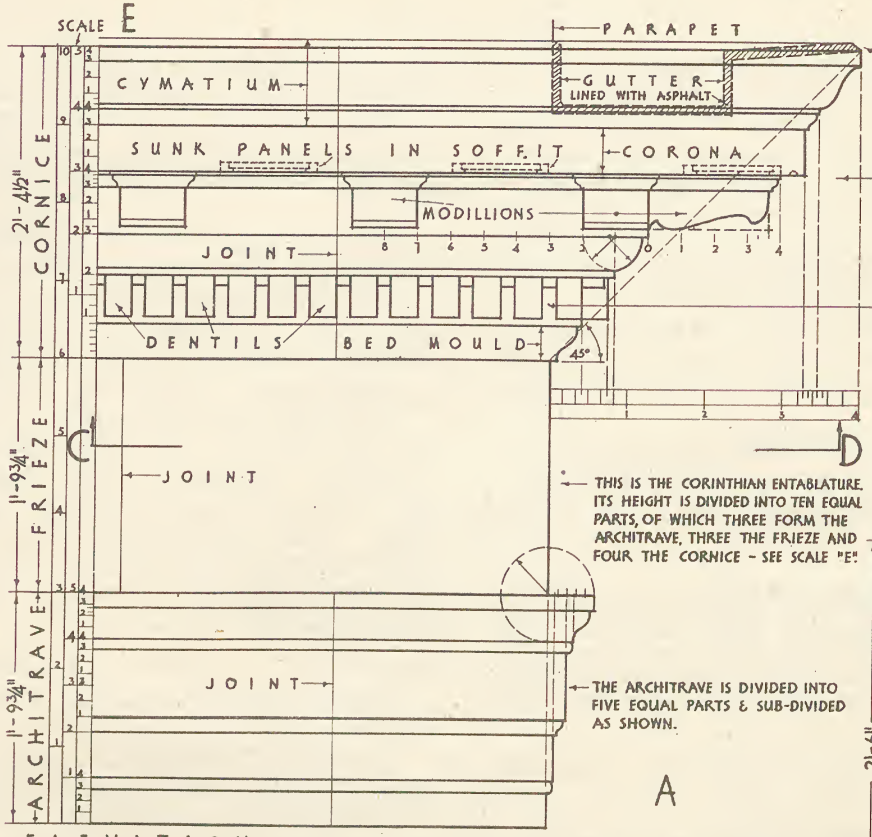
CORNICES



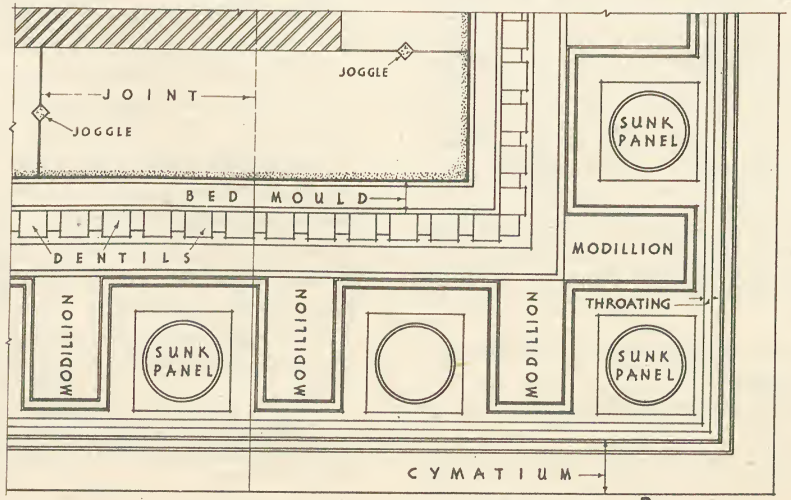







SCALE
E
PARAPET
CYMATIUM
GUTTER LINED WITH ASPHALT
SUNK PANELS IN SOFFIT
CORONA
MODILLIONS
JOINT
DENTILS
BED MOULD
45°
2'-4½" CORNICE
1'-9¾" FRIEZE
1'-9¾" ARCHITRAVE
C
D
JOINT
JOINT
A
ALTERNATIVELY, THE WEATHERING MAY BE AS SHOWN AT "L"
THE CORNICE IS DIVIDED INTO FIVE EQUAL PARTS & SUB-DIVIDED AS SHOWN.
THE SPACE BETWEEN THE DENTILS EQUALS HALF THEIR WIDTH.
THIS IS THE CORINTHIAN ENTABLATURE. ITS HEIGHT IS DIVIDED INTO TEN EQUAL PARTS, OF WHICH THREE FORM THE ARCHITRAVE, THREE THE FRIEZE AND FOUR THE CORNICE - SEE SCALE "E".
THE ARCHITRAVE IS DIVIDED INTO FIVE EQUAL PARTS & SUB-DIVIDED AS SHOWN.

ELEVATION OF CLASSIC ENTABLATURE



PLAN AT "C D" (LOOKING UP) B

SCALE FEET

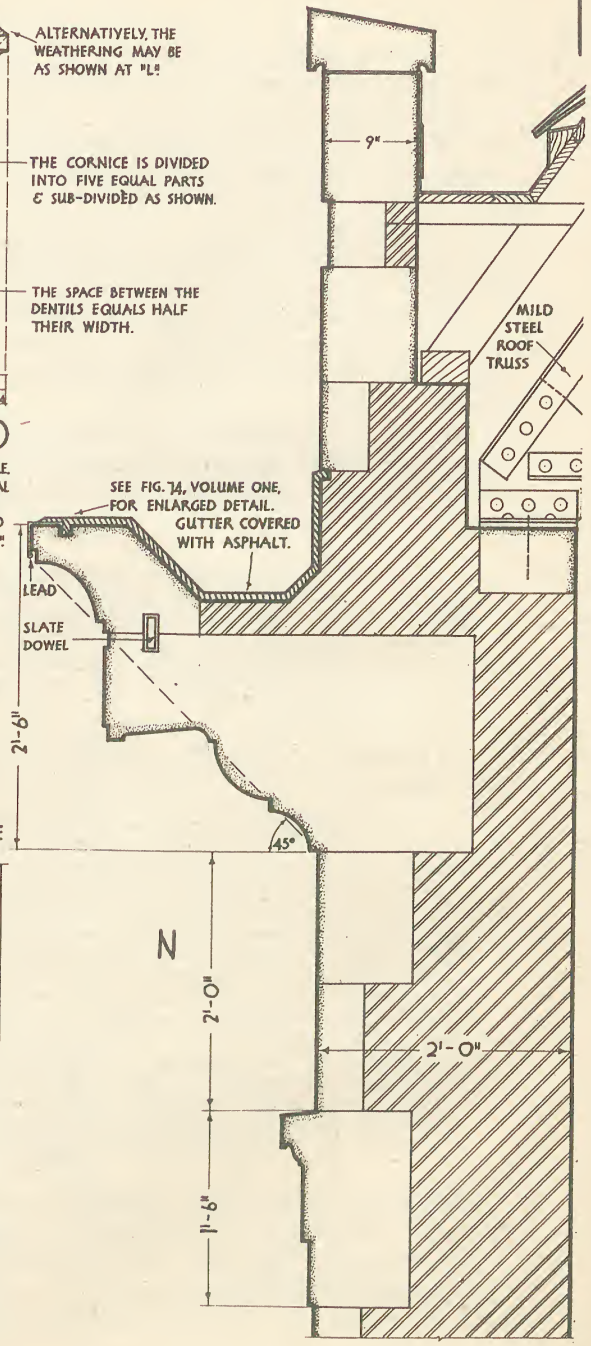


FIGURE 43.

fluted band. A somewhat similar motif is used at the cornice K. Cornice L has a relatively large projection; the soffit of this type may be relieved by raised panels or *mutules*.

The section at N shows a cornice complete with parapet, etc. An economy in stone results when a cornice is of this compound type, as a relatively small block is required as a crowning member.

It will be noticed that all of these cornices are throated to prevent staining of the masonry below.

STONE STEPS AND STAIRS

The design and construction of wood stairs are described in pp. 78-97, Vol. III, and there illustrated in Figs. 29-39 inclusive. As the terms, essential requirements, proportions of steps, etc., are dealt with in that volume, and as they apply equally well to stone steps and stairs, it is unnecessary to repeat such information here, and students are therefore recommended to defer consideration of the following until they have studied the principles of wood stair construction.

The stone selected for steps and landings must be hard, strong and durable, and it should not readily wear to a smooth and slippery surface. Certain of the sandstones best satisfy these requirements, and " York " stone (see p. 89) is usually specified.

STEPS are either (1) rectangular, (2) built-up, or (3) spandril in cross-section.

1. *Rectangular Steps*.—These are illustrated at H, J, K, L, M, N and O, Fig. 44, Fig. 38 and in Vol. I. They are the strongest type. A flight of such solid steps may be constructed with the front lower edge of one step supported on the top back edge of that below (see L and N, Fig. 44), but the rebated or checked joint (similar to that at G, Fig. 44) is the best. These steps may be provided with moulded nosings (see G and H, Fig. 44, Fig. 37 and Fig. 38).

2. *Built-up Steps* (see E and P, Fig. 44).—The tread and riser of each step are formed of relatively thin sawn slabs, and the construction is therefore economical. They are not so strong as solid rectangular steps, and whilst occasionally used without any bedding or backing (see P), they are more often applied as a facing to concrete steps (see E). The minimum thickness of treads which are only supported at the ends is 2-in. and this should be increased by at least ½-in. for every extra foot of unsupported length beyond 3-ft. Slabs which are less than 2-in. thick can be easily fractured, even when being handled before and during fixing, and thin treads constructed as shown at E can readily snap by a weight suddenly applied unless solidly bedded throughout.

Steps formed of stone treads only, known as *skeleton stone steps*, are sometimes employed for short, narrow flights, which are not subjected to heavy traffic and where the absence of risers is not objected to.

3. *Spandril Steps* (see A, B, C, D and E, Fig. 45).—Excepting the ends which are built into the wall, these steps are approximately triangular in cross-section, and are therefore lighter than the solid rectangular type. Such steps add greatly to the appearance of a stair and the maximum headroom is obtained by their use. The soffit may be flush (see A and B), broken (see C) or moulded (see D). A splayed rebated joint is formed between each step, the splay of the rebate being normal to the pitch of the stair. To avoid weak construction and damage to the step at its back edge (where it is thinnest), it is usual to have a 2-in. splay (see A) for stairs not exceeding 4-ft. in width, and this is increased by ½-in. for every additional foot in width.

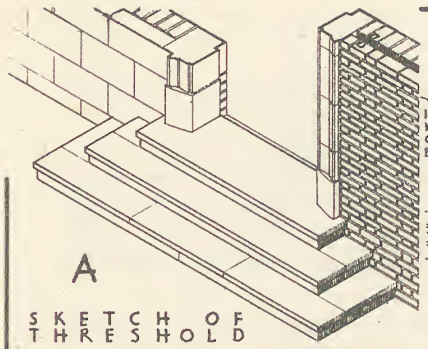
THRESHOLDS.—In addition to those illustrated in Vol. I, there are several thresholds shown in Figs. 37, 38 and 44. An example of one in which built-up steps are employed is shown at A, B, C, D and E, Fig. 44. The treads and risers are solidly bedded and well jointed in cement mortar (1 cement to 3 sand). The treads of all external steps should be given a slight fall to throw off the weather; the fall shown at E is ⅛-in. The top edge of the nosing should be slightly rounded off (it is sometimes chamfered), otherwise it may be easily damaged. The nosings may be moulded; several examples of moulded nosings are shown at G, Fig. 44. A, B, C, D, K, L and M, Fig. 45, Fig. 37 and Fig. 38. Solid rectangular steps may also be used as an alternative. Alternative facings to the wall are shown, that on the left being of ashlar with a brick backing, and on the right a brick cavity wall is shown, having a Flemish garden wall facing (see B, Fig. 18).

The application of solid rectangular steps forming an unimportant entrance is shown at L, M, N and O, Fig. 44. The steps are built solidly into a wall at one end and supported at the other by a dwarf wall (see L and M). The front lower edge of one step is bedded in cement mortar on the top back edge of the step below (see N). Whilst this form of joint is good enough for a flight of this description, it is not employed in first-class work as open joints appear if the mortar bedding becomes defective. Note that the going (10-in.), plus twice the rise (7-in.) as shown at N, equals 24-in. (see p. 82, Vol. III).

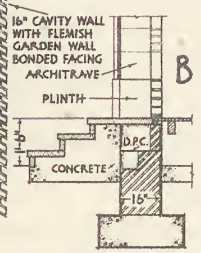
The detail at P shows the construction of built-up steps which could be adopted as an alternative to the above. The treads and risers are connected together by means of three pairs of copper (or slate or other non-corrodible material) cramps or dowels bedded in cement mortar.

The simple balustrade consists of 1-in. square wrought iron balusters to which a handrail of similar material is screwed (see K, Fig. 45), holes being drilled through the handrail and the ends of the balusters (which would also be tapped) to receive the screws; one end of the rail is also built into the wall to ensure greater rigidity. The balusters are secured to the steps and landing in a manner shown at K and M, Fig. 45; dovetailed mortices are formed to receive the ends (preferably ragged to give a key) of the balusters; molten lead is then run in, well caulked (consolidated when cool with a blunt chisel) and covered flush with cement mortar to exclude water from the lead and thus prevent discoloration of the stone. Grouted cement is a cheaper alternative to lead. As an alternative to the metal balustrade, the wall may be continued to a convenient height and finished with a coping.

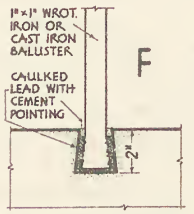
STONE STEPS



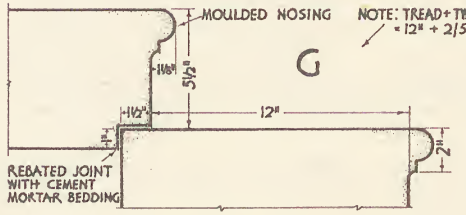
SKETCH OF THRESHOLD



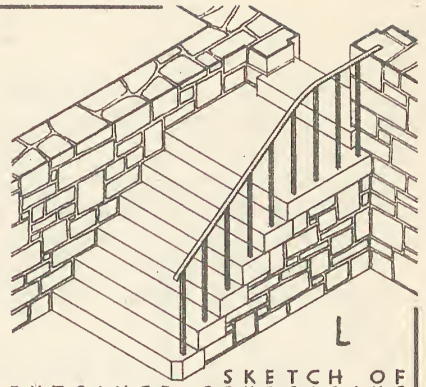
SECTION "RR"



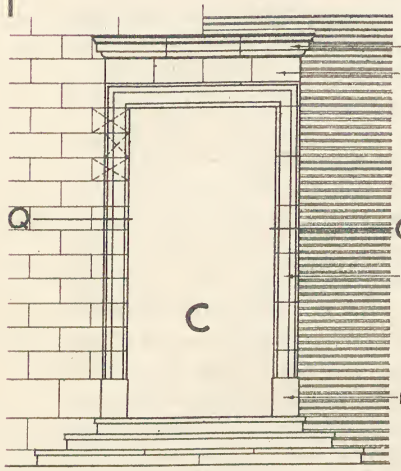
METHOD OF FIXING BALUSTERS



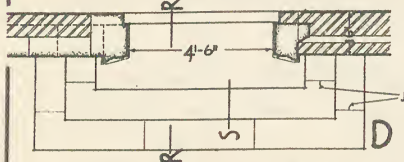
DETAIL "T"



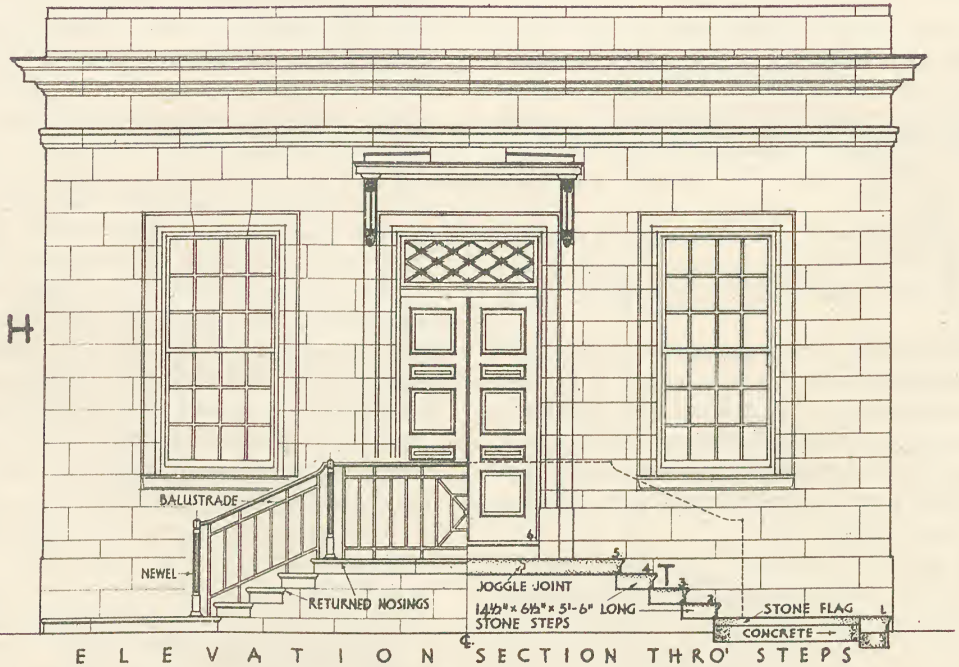
SKETCH OF ENTRANCE COMPRISING RECTANGULAR STEPS



ELEVATION

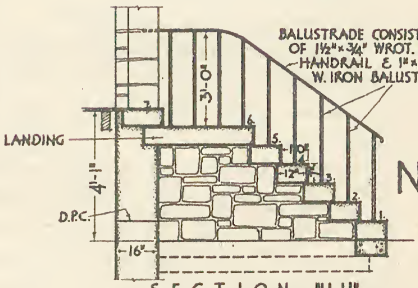


PLAN "QQ"

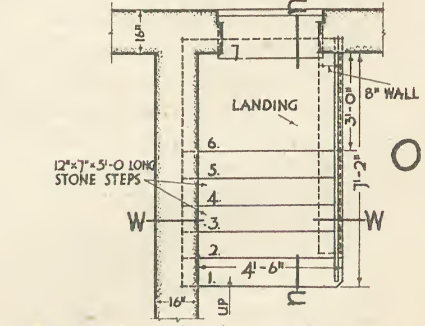


ELEVATION SECTION THRO' STEPS

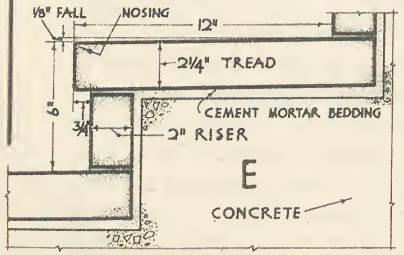
SECTION "W W"



SECTION "U U"

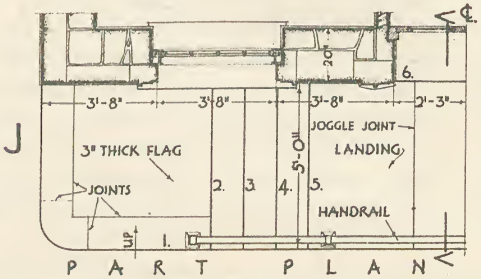


PLAN

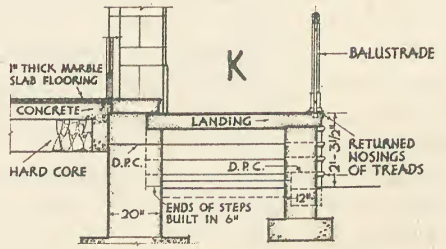


SECTION "S"

BUILT-UP STEPS

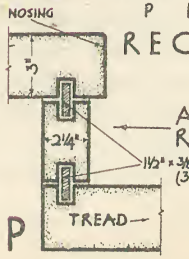


PART PLAN



SECTION "V V"

REBATED RECTANGULAR STEPS WITH RETURNED NOSINGS



RECTANGULAR STEPS

ALTERNATIVE TO RECTANGULAR STEPS

1½" x ⅜" DIA. COPPER CRAMPS (3 PAIRS PER RISER)

SCALE FOR E, F, G & P — INCHES

SCALE FOR A, B, C, D, H, J, K, L, M, N & O — FEET

NOTE: THE DOORWAY AT "A", "C" & "D" SHOWS ALTERNATIVE STONE & BRICK FACINGS; THE JOINTS IN THE ARCHITRAVE COURSE WITH THOSE OF THE BRICKWORK. THE BUILDING AT "H" SHOWS TWO ALTERNATIVE TREATMENTS OF THE ASHLAR, THAT ON THE LEFT CONSISTING CHIEFLY OF EQUAL COURSES & THAT ON THE RIGHT OF ALTERNATE WIDE & NARROW COURSES.

FIGURE 44

Stone steps are used externally in areas to basements, heating chambers, etc.

Another application of rectangular steps is given at H, J and K, Fig. 44. The elevation is that of the façade of a small public building, such as offices or a bank. Whilst this is not a common arrangement of steps for an entrance, it is given here as an alternative to the more usual form shown at C, and it has an advantage in that the balustrade is useful, especially to the infirm and older members of the public who may visit the building. A detail of the steps is given at G ; these are of good proportions, with the bottom of the front edges square rebated and the tread nosings moulded ; these nosings are returned on the outer ends of the step (see H and K). The steps and landing are built 6-in. into the main wall and are supported on a wall at the outer ends. The landing consists of three stone slabs (see H and J) connected together by *joggle joints* (see the section at H and also the detail at F, Fig. 45). Each bottom step consists of an edging of stone blocks cut to the section shown at G, with a 2 or 3-in. thick flag solidly bedded on a concrete bed (see section at H). The metal balustrade is secured to the steps as described on p. 115. Alternative designs of the latter are shown in Fig. 45.

STAIRS.—Stone was commonly preferred to timber in the construction of principal staircases of municipal and commercial, etc., buildings. This material has been largely superseded and such stairs are now chiefly of reinforced concrete construction (see p. 120). Where stone is still specified for this purpose, it is generally in districts where suitable local sandstone is employed.

A stone open well stair is detailed in Fig. 45. The plan H shows twenty steps, including landings, arranged round a 2-ft. 4-in. wide well. As shown in the sections G and J, these steps are of the spandril type already described. They are also known as *cantilever* or *hanging steps*, as each is fixed at one end only, the other being free and finished with a returned moulded nosing as detailed at A. The sketch at E shows the built-in end of a spandril step ; the spandril soffit is stopped at the face of the wall (or plaster) and a square seating is formed at the end which is built into the wall (which latter is preferably constructed in cement mortar), the wall hold varying from $4\frac{1}{2}$ to 9-in. The ends of these steps are bedded in cement and solidly fixed all round—especially at their top surfaces—with sound pieces of slate, etc. set in cement ; the steps are also jointed in mortar.

Each of the alternative spandril steps shown at B has its returned nosing continued to line with the face of the riser of the second step above it. Of good appearance, they are stronger than those at A because of their increased thickness. The steps at C form a broken soffit, the appearance of which is less satisfactory than the above. The moulded soffit formed by the steps at D is attractive. Alternative nosings are shown at C, K, L and M, the bold appearance of the latter being especially effective (see C, Fig. 37 and H, Fig. 38.) Note that the proportions of these steps agree with the rules stated on p. 82, Vol. III.

The half space landing consists of four slabs, joggle jointed, which are solidly built into the walls. The thickness of this landing may be either $6\frac{1}{2}$ or $8\frac{1}{4}$-in. (see R) ; whilst the latter gives a satisfactory finish on the underside where it joins step 19, it results in a large increase in weight of each slab. The joggles are stopped at the free ends at least, and thus only butt joints are exposed, as shown at F. Each of the quarter space landings may consist of two slabs, joggle jointed, to facilitate handling and fixing.

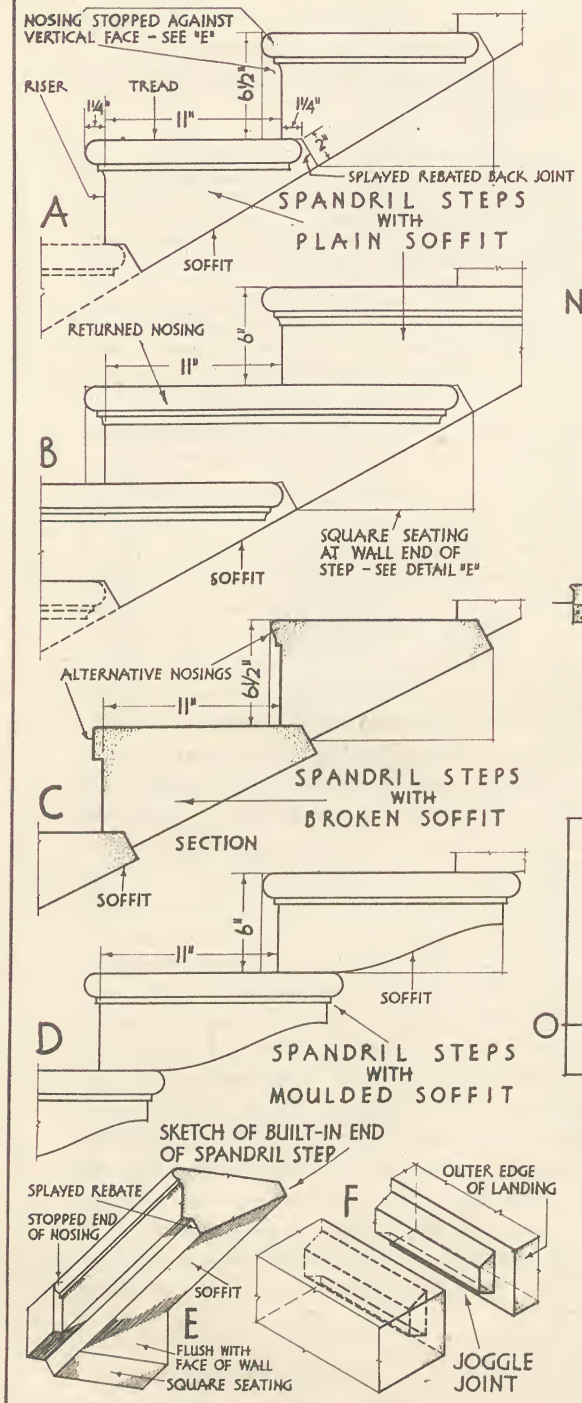
The steps may be built-in as the walls are being constructed, or fixing may be deferred until the walls have been built and the building is nearer completion. The latter is the usual course adopted and risk of damage to the steps is thereby minimized ; the pockets which receive the ends of the steps are formed and temporarily filled in with bricks laid in sand as the walling proceeds, which bricks are thereby easily removed when required. A storey-rod is used to ensure that the steps are built in at the correct heights (the bottom one being fixed first) and the free ends of the steps are securely strutted down to the floor ; these vertical wood struts must not be removed until the work has set. If built-in as the general work proceeds, the steps must be adequately protected with rough wood casings ; these must be well secured and should be frequently examined, as a dislodged casing may result in a damaged nosing.

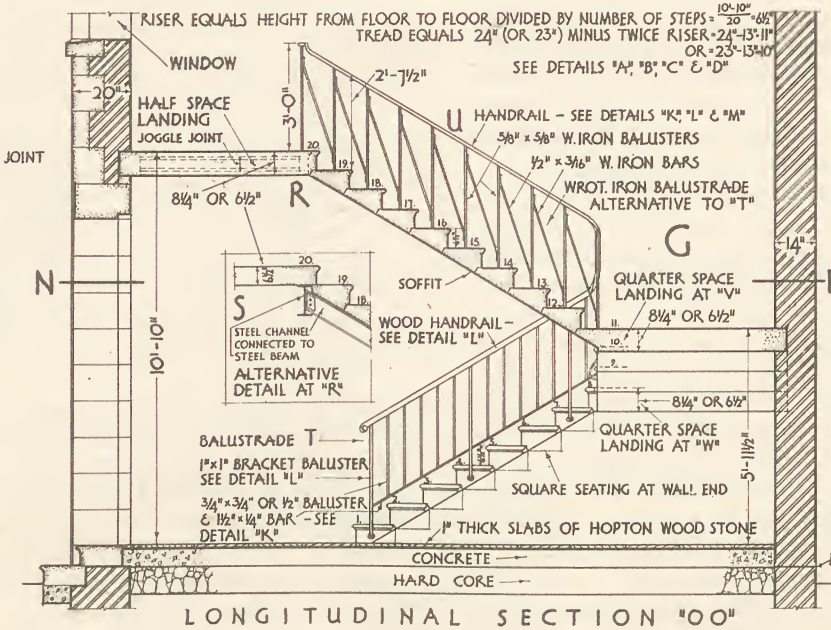
The weight of wall tailing down the fixed ends of the steps must be adequate to ensure stability of a cantilevered stair. The strength of the stair shown in Fig. 45 would be considerably increased if, as shown at S, a mild steel beam was provided to support the half space landing at its outer edge and a steel channel or beam was introduced at the soffit of each flight and near to the free ends of the steps. The detail S shows the connection between the landing beam (which would have a 9-in. bearing on the walls) and the top flight channel. Such steelwork is necessary for wide stairs, especially if subjected to heavy traffic. Incidentally, it assists in preventing a total collapse of the stair in the case of fire. If desired, such steelwork may be encased in concrete and either plastered or finished with thin stone slabs bedded to the concrete, as shown at B, Fig. 46.

BALUSTRADE.—Two alternative designs of wrought iron balustrades are shown at G and J, Fig. 45, and alternative details of these are shown at K, L and M. The fixing of the balusters at K has been described on p. 115 ; as indicated, the dovetail mortice which receives the baluster must be set back from the end face of the step (unless the nosing is of the type shown at M). This reduces the effective width of the stair, and to avoid this the balustrade may be of the design shown at G and J where balusters of small section, connected at their lower ends to a $1\frac{1}{2}$-in. by $\frac{1}{4}$-in. bar, alternate at intervals with 1-in. square *bracket balusters*. The latter are so called because they are connected to the *ends* of the steps in a similar manner to that described, the balusters being curved to clear the nosings (see also detail L) ; the cover plate shown may be used to provide a good finish and it may be either bedded on cement or fixed by small screws secured to plugs driven into holes drilled into the stone. This detail also shows the method of fixing a wood handrail to a metal balustrade ; the upper ends of the balusters are screwed to a $1\frac{1}{4}$-in. by $\frac{1}{4}$-in. wrought iron bar and the handrail is secured to this with screws, the latter being fixed from below at intervals between the balusters. An alternative wood handrail, fixed in a similar manner, is shown at M. The balustrade may be of bronze as an alternative to wrought iron (see also B, Fig. 46).

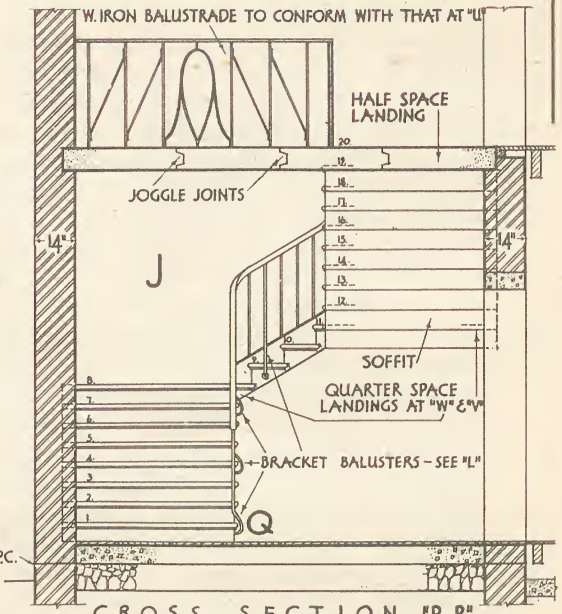
The brick walls of this staircase may be either plastered or faced with ashlar

STONE OPEN WELL STAIRCASE

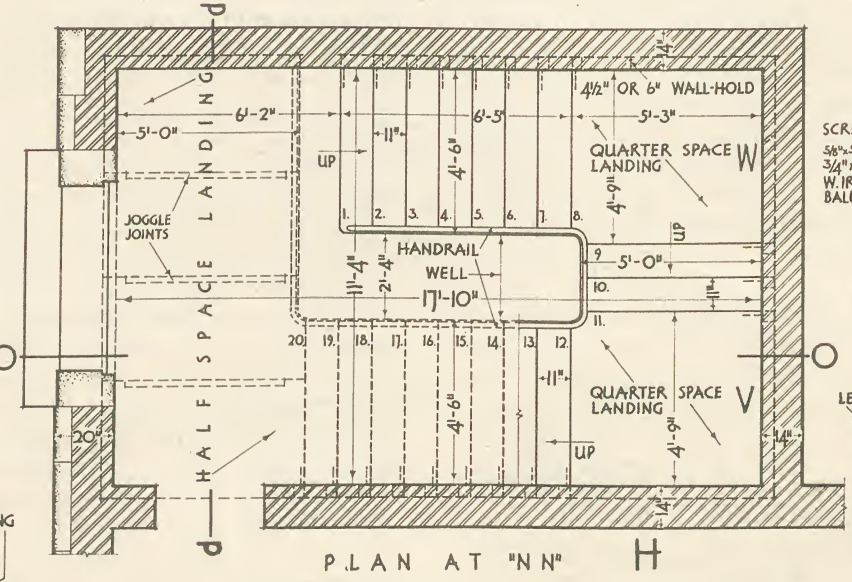


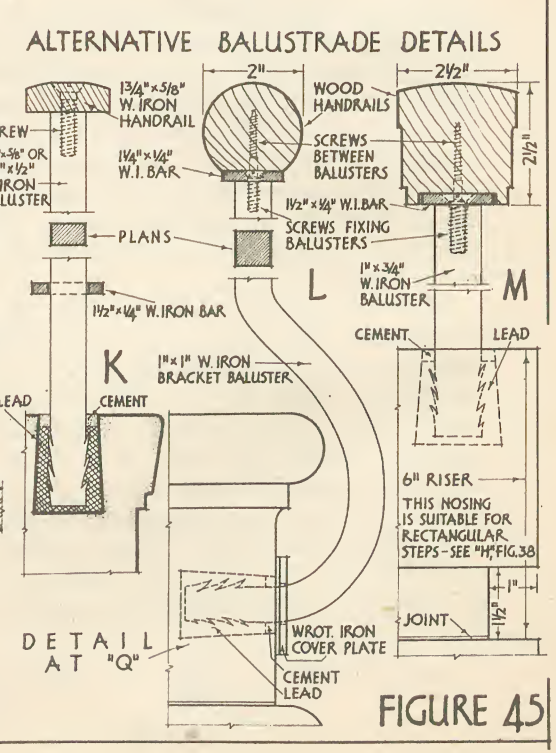

RISER EQUALS HEIGHT FROM FLOOR TO FLOOR DIVIDED BY NUMBER OF STEPS = 10'-10" / 20 = 6½"
TREAD EQUALS 24" (OR 23") MINUS TWICE RISER = 24"-13'-11" OR = 23"-13'-10"
WINDOW
SEE DETAILS "A", "B", "C" & "D"
HALF SPACE LANDING
JOGGLE JOINT
3'-0"
2'-7½"
U
HANDRAIL – SEE DETAILS "K", "L" & "M"
5/8" x 5/8" W. IRON BALLUSTERS
½" x 3/16" W. IRON BARS
WROT. IRON BALUSTRADE ALTERNATIVE TO "T"
8¼" OR 6½"
R
G
N
N
S
STEEL CHANNEL CONNECTED TO STEEL BEAM
ALTERNATIVE DETAIL AT "R"
SOFFIT
WOOD HANDRAIL – SEE DETAIL "L"
QUARTER SPACE LANDING AT "V"
8¼" OR 6½"
101'-10"
8¼" OR 6½"
QUARTER SPACE LANDING AT "W"
BALLUSTRADE T
1"x1" BRACKET BALUSTER SEE DETAIL "L"
3/4"x3/4" OR ½" BALUSTER & ½"x¼" BAR – SEE DETAIL "K"
SQUARE SEATING AT WALL END
5'-11½"
1" THICK SLABS OF HOPTON WOOD STONE
CONCRETE
HARD CORE
D.P.C.

LONGITUDINAL SECTION "OO"



CROSS SECTION "P P"





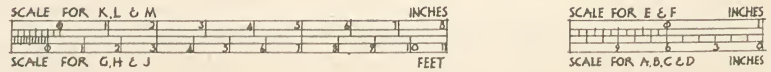


FIGURE 45

REINFORCED CONCRETE & MARBLE STAIRCASE

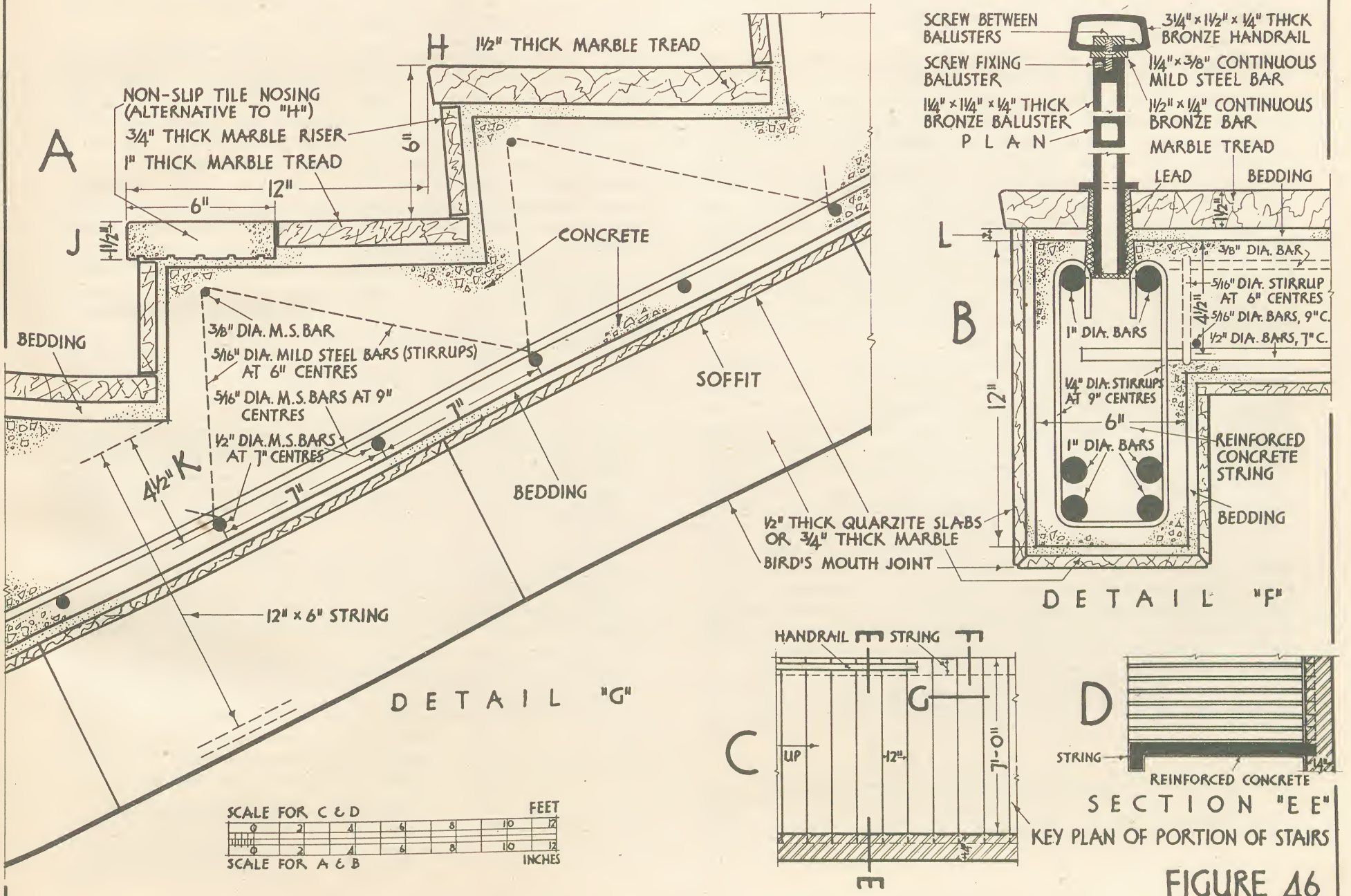


FIGURE 46

of similar stone to that of the steps. If left exposed, the brickwork would be finished with flush mortar joints. As shown, the floor covering can be of stone slabs bedded on concrete.

If there is not sufficient width available for an open well stair, it would be designed of the dog-leg type (see B, Fig. 29, Vol. III).

Reinforced Concrete Stairs.—It has been already stated that important stairs, especially those required for public buildings, are now constructed of reinforced concrete and that this has largely replaced masonry for this purpose. The reasons for this are : A reinforced concrete stair, suitably finished, (1) has a more attractive appearance, (2) it may be more fire-resistant, (3) its width is less restricted, as it can be designed to take heavy traffic over a large transverse span without resorting to any intermediate support (such as walls which encroach upon the hall), (4) the treads can be rendered non-slip (stone treads wear smooth and may become dangerous), and (5) it can be more easily kept clean.

Although reinforced concrete design is deferred until the advanced years of a course, a stair of contemporary construction is briefly referred to here in order that a comparison may be made between stairs of traditional design and those in which newer materials are employed.

A key part plan and cross-section of a portion of a flight of a *typical* open well reinforced concrete stair are shown at C and D, Fig. 46. The section shows the structure to be built into the wall at one end and supported by a string at the other. The details show that the concrete (which resists the compression stresses) is reinforced with $\frac{1}{2}$-in. diameter mild steel transverse bars (which resist the tension stresses) at 7-in. centres ; $\frac{5}{16}$-in. diameter longitudinal bars are placed immediately over and wired to these transverse bars at 9-in. centres ; $\frac{5}{16}$-in. diameter bars, called *stirrups*, are wired at 6-in. centres to the $\frac{1}{2}$-in. diameter bars and $\frac{3}{8}$-in. diameter transverse bars placed near to the top corners of the concrete steps ; the thickness of the concrete at K is $4\frac{1}{2}$-in. ; the upper surface of the concrete is shaped to suit the risers—two alternative forms being shown at A. The concrete string is reinforced with four 1-in. diameter steel longitudinal (tension) bars and two similar (compression) bars near the top surface ; $\frac{1}{4}$-in. diameter steel stirrups are wired to these bars at 9-in. centres and at right angles to the pitch of the stair. *Note, the above sizes vary according to the width of the stair and the load to be supported*, and are determined by calculation.

Because of its unattractive appearance a stair constructed entirely of reinforced concrete would not be suitable for a public building in which it was to be an important feature. Hence the structure is covered or veneered with marble, tiles, terrazzo or other suitable material.

Detail A shows alternative forms of risers, one being vertical and the other inclined. These risers are formed of $\frac{3}{4}$-in. thick slabs of marble bedded to the concrete. The tread at H is formed of a $1\frac{1}{2}$-in. thick slab of marble, solidly bedded. As polished marble, especially when wet, has a slippery surface, non-slip tile nosings, which are artificial products, are often incorporated with the treads ; that shown at J is grooved to give a key for the bedding. Care must be taken to use a mortar for bedding which will not stain the marble.

The string and soffit are also shown covered with marble or quartzite (a natural very hard stone, imported from Italy, and obtainable in several attractive colours—see p. 97) slabs. The walls may also be covered with $\frac{3}{4}$-in. thick marble, etc., slabs.

As these covering materials are costly, the soffit may be finished with Keene's or similar cement.

The string shown is of the " open " type ; " close " strings (see p. 80, Vol. III) may be employed.

Expensive veneers are only applied when the appearance is of importance. Reinforced concrete stairs, such as are required for warehouses, etc., are often left uncovered, the treads only being provided with non-slip nosings.

The stair shown in Fig. 46 is cast *in situ*, *i.e.*, it is constructed on the site. It is therefore necessary to provide a temporary wood support, called *formwork* or *shuttering*, for this purpose. Briefly, this consists of butt-jointed boards or sheets for the soffit, fixed at the correct level and pitch to bearers supported by struts. This would be continued to form a suitable frame or box for the string, and this would be strutted ; riser boards, etc., would also be fixed. The concrete is placed in position after the reinforcement has been fixed, and the formwork is not removed until the concrete has adequately set.

Concrete steps for narrow stairs are often pre-cast, *i.e.*, are separately formed in wood moulds of the required shape. These, when sufficiently set, are removed and fixed as described for stone steps.

Details of the bronze balusters and handrails are shown at B. These are alternative to those illustrated in Fig. 45 and are fixed as previously described.

Note.—The section through the string at B has been taken at a normal from the intersection between the concrete tread and riser (bottom). The baluster has been shown in section to illustrate more clearly the construction ; as this would be in the centre of the tread, the distance L would be approximately 4-in., and therefore the bottom of the baluster is well clear of the top main reinforcement.

CHAPTER FOUR

MILD STEEL ROOF TRUSSES

Syllabus.—Mild steel roof trusses up to 40-ft.[1] span, with alternative details.

MILD steel [2] is much stronger than timber, it is more fire-resisting and its sections can be readily assembled to form comparatively simple connections. It is principally for these reasons that mild steel is now employed extensively for roof trusses of small and medium spans and for its supersedence of wood as a material for trusses of large span.[3] Whilst wood is still preferred to steel for trusses of open (unceiled) roofs of certain buildings, well-designed steel trusses for large spanned open roofs of buildings of the industrial, etc., type have a light and satisfactory appearance, chiefly because of the small size of the members and the simple joints. Mild steel roof trusses must be painted at intervals to prevent corrosion.

A steel roof truss, like a wood king post roof truss (see p. 76, Vol. I), is a triangulated structure. The principal rafters (abbreviated to " rafters ") are prevented from spreading by connecting their lower ends by a tie (*main tie*), and struts and subsidiary ties are provided at intermediate points to afford adequate bracing. Struts should be kept as short as possible. The centre line principle is adopted throughout (see p. 122), and thus the point of attachment of each purlin coincides with the intersection of the axes of the truss members. Secondary stresses, such as bending moments in the rafters, are thereby avoided.

All of the members of a modern metal roof truss are of mild steel, and most, if not all, of them are angles (see D and E, Fig. 77, Vol. I). Angles effectively resist both compression and tension stresses ; they can be conveniently attached and they are produced economically. Thus, whereas formerly T-bars were used for rafters, either a single angle or two angles placed back to back are now employed. Struts consist of either single or double angles, and either one or two angles placed back to back are used for a main tie. Until comparatively recently, it was a common practice to use single or double flat bars for a main tie, as they were suitable for resisting tension stresses. However, owing to wind pressure and the abnormal strain imposed during the transporting and erection of trusses, members may be subjected to changes of stresses, and flats will not resist compression. *Flat main ties therefore tend to become buckled.* If a ceiling is to be provided, ceiling joists can be readily fixed to a main tie of double angles (see F, Fig. 49), and this is an additional reason why they should be used instead of flats, which latter are useless for this purpose unless metallic lathing instead of wood laths is employed. Flat bars are still used, but less frequently than formerly, for subsidiary tie members (see Fig. 50) ; angles are preferred.

The members of a truss are connected together by means of rivets or bolts [1] and thin plates, called *gussets*.

The *pitch* of rivets is the distance between their centres. According to the British Standard Specification for " The Use of Structural Steel in Building," No. 449—1937, (*a*) the minimum pitch shall be not less than three times the diameter of the rivets, (*b*) the maximum pitch is 6-in. for compression members and 8-in. for tension members, and (*c*) the minimum distance from the centre of any rivet or bolt to the end of a member or edge of a gusset shall be $1\frac{1}{8}$-in. and $1\frac{1}{4}$-in. for $\frac{5}{8}$-in. and $\frac{3}{4}$-in. diameter rivets respectively. The size of the rivets and bolts depends upon that of the members to be connected, thus $\frac{5}{8}$-in. diameter rivets are commonly employed for angles and flats up to $2\frac{1}{2}$-in. wide and $\frac{3}{4}$-in. diameter rivets and bolts for larger members. When riveting is employed, a member, even if subjected to a small stress, should be connected to a gusset by at least two rivets. Riveting can thereby be facilitated by the placing of a temporary bolt in the second hole, which is subsequently replaced by a rivet. Further, if one of the rivets is defective the second prevents failure of the joint.

The thickness of gussets theoretically depends upon the bearing value of the rivets employed. The minimum thickness is $\frac{1}{4}$-in. and these have been used for the small truss detailed in Fig. 47 ; $\frac{5}{16}$-in. gussets are used for roofs of larger span up to at least 40-ft. and the thickness rarely exceeds $\frac{3}{8}$-in. even for very large trusses. The size and shape vary according to the pitch of the rivets,

[1] In many syllabuses the span is limited to 30-ft.

[2] The manufacture and characteristics of mild steel and other metals are described in Vol. IV.

[3] An exception is the bow-string or similar laminated wood type of truss which is still occasionally adopted for large spans.

[1] Welding, as an alternative to riveting and bolting, is a comparatively recent development. Gussets are dispensed with and the members, all angles, are welded together. Thus, referring to the detail at T, Fig. 50, the ties and strut would be connected directly on to the rafter by means of *fillet welds*. An electric current or gas (an oxy-acetylene flame) is employed to melt a steel rod or wire (called an *electrode*) and the adjacent edges of the members in such a manner that the molten metal from the electrode is deposited along the points of contact and fused into them.

size and inclination of the connecting members and the appearance desired. Several examples of gussets are given in Figs. 47-50 and will be referred to later. If a member consists of double angles, gussets are always placed between them.

Small trusses are fabricated (riveted or bolted together) at the works and transported to the site. Owing to the difficulty of conveying larger trusses, these are fabricated in parts at the works and assembled together on the job (see the reference to Fig. 50 on p. 128). Sometimes trusses are made " piece small," *i.e.*, the various members, cut to length and holed for the bolts or rivets, are conveyed to the site and the trusses are there assembled.

Trusses are erected by a crane (or sheer legs) and connected by holding-down bolts to the building (see below). The distance between trusses up to 40-ft. span varies from 10 to 15-ft. Wider spacing results in heavy purlins and uneconomical sizes of members. The pitch of steel roof trusses, like those of timber construction, depends upon the nature of the covering material and the architectural effect desired.

Details of roof trusses up to 40-ft. span are given in Figs. 47-50. These are typical only, and several alternative details are provided for reference. It is appreciated that the sizes of the members are influenced by the weight of the covering material,[1] the distance between the trusses and purlins, the provision or otherwise of a plastered ceiling, and the degree of exposure of the building to wind pressure. Briefly, the sizes of the members, number and sizes of the rivets, etc., are dependent upon the forces in the members. The trusses illustrated in Figs. 47, 48, 49 and 50 have been designed to support ceilings, and in each example the covering material is slates.

TRUSS SUITABLE FOR A 20-FT. SPAN (see Fig. 47).—This is a slated roof, having a pitch of 30°. The effective span (distance between the centres of bearings) is 20-ft. and the maximum distance between the trusses is 12-ft. It is assumed that the building is of the single storied workshop type and the external walls are only required to be 9-in. thick (see S). Increased bearings for the trusses are provided by internal piers, as shown. If required to prevent the transmission of moisture, the walls would have to be rough-casted (or similarly treated) externally, or be increased in thickness as shown at C, Fig. 48, or be of cavity construction (see Fig. 49).

Sound sandstone pads of sufficient thickness and area must be provided to give a reliable and level bearing for the ends of the truss and to receive the steel fixing bolts. The pads course with the brickwork. The bolts are called *ragged lewis bolts* or *rag bolts*.[2] A sketch of one of these holding-down bolts is shown at B ; its thickness is equal to the diameter of the upper threaded shank and the lower portion is tapered in its width ; its edges are jagged as shown to afford a key for the fixing material, which is usually molten lead run in to secure the bolt when placed in the hole in the padstone. The lead should be well caulked, otherwise water may enter and set up corrosion which may split the padstone. These bolts, which are provided with nuts, are obtainable in overall lengths of 4, 6, 9, 12 and 15-in. and of $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, 1 and $1\frac{1}{4}$-in. diameter. That shown at B is suitable for the truss illustrated in Fig. 50, but as indicated at C, Fig. 47, smaller bolts will serve for this small truss. Two are required at each end and these are fixed in readiness to receive the truss.

All of the members consist of single angles. These and the gussets are only $\frac{1}{4}$-in. thick, the minimum thickness stipulated in the aforementioned B.S.S. No. 449. The preferred maximum unsupported length of the wood spars is 8-ft. (see p. 73, Vol. I), and therefore only one purlin is required at each side.

The centre line principle has been observed in setting out, and, to prevent confusion, these lines have been shown to be those of the rivets.

> Although the centre lines of members are taken when drawing force diagrams, it should be pointed out that the details of a structural engineer's working drawing, on which the position of each rivet hole at every connection is indicated, show the intersecting lines of members to be what are termed *gauge lines*, *scratch lines* or *scratters*. These are the setting out lines which are " scratched " on the *backs* of members at the fabricating shop and along which the centres of the holes for the rivets are spaced. The following bracketed figures give the position (measured down the back from the intersection between the two legs) of the gauge lines for angles having 2-in. ($1\frac{1}{8}$-in.—see H, Fig. 48), $2\frac{1}{4}$-in. ($1\frac{1}{4}$-in.), $2\frac{1}{2}$-in. ($1\frac{3}{8}$-in.—see C, Fig. 47), 3-in. ($1\frac{3}{4}$-in.—see C), $3\frac{1}{2}$-in. (2-in.), 4-in. ($2\frac{1}{4}$-in.), etc., legs. The setting out of the details in Fig. 50 shows the intersecting lines to be those of the scratter lines.

It will be observed that at A, Fig. 47, in order to obtain symmetry, the rafters and inclined tension angles (known as *diagonal ties*) are fixed to the gusset plates on one side, and that the main tension angle, called the *main tie*, and the struts are fixed on the other. This results in a better balanced truss than if all the members were fixed on the same side.

Details of the foot or *shoe* of the truss are shown at C, D and E. A short angle *cleat* is fixed at each side of the gusset and these rest upon a *bearing plate* or *base plate* or *sole plate*. Both the cleats and the bearing plate are holed at a distance apart equal to that of the lewis bolts, *i.e.*, $3\frac{3}{4}$-in. (see E). The plates are placed in position and the truss is hoisted and lowered until the holes in the cleats are engaged by the shanks of the lewis bolts. The cleat holes are larger than the diameter of the bolts (see D) to facilitate fixing and allow a slight margin for any error in the setting out. This obviates an erection difficulty which would be otherwise caused if such an allowance was not made and a slight inaccuracy occurred in either the setting out of the lewis bolts or the position of the holes in the cleats. The nuts are finally tightened with a spanner. The section at E shows the rafter at one side of the gusset and the main tie at the other.

The details at the apex are shown at F and G. The ends of the rafters are mitred and those of the diagonal ties are square cut. The wood ridge is secured by two $\frac{1}{2}$-in. diameter bolts to two bent plates or flats which have been either

[1] The weight of asbestos-cement corrugated sheets is approximately $3\frac{1}{2}$-lb. per sq. ft. and that of clay tiles may be as much as $14\frac{1}{2}$-lb. per sq. ft. Thus, if the trusses are 12-ft. apart and the purlins are at 8-ft. centres, the difference in weight of these covering materials (ignoring that of the spars necessary for the tiles and not required for the sheets) over the area concerned is approximately half a ton.

[2] A " rag bolt," unlike a lewis bolt, is not tapered, and resembles an ordinary bolt shank, part of which is jagged and part threaded.

STEEL ROOF TRUSS

SUITABLE FOR A 20-FT. SPAN

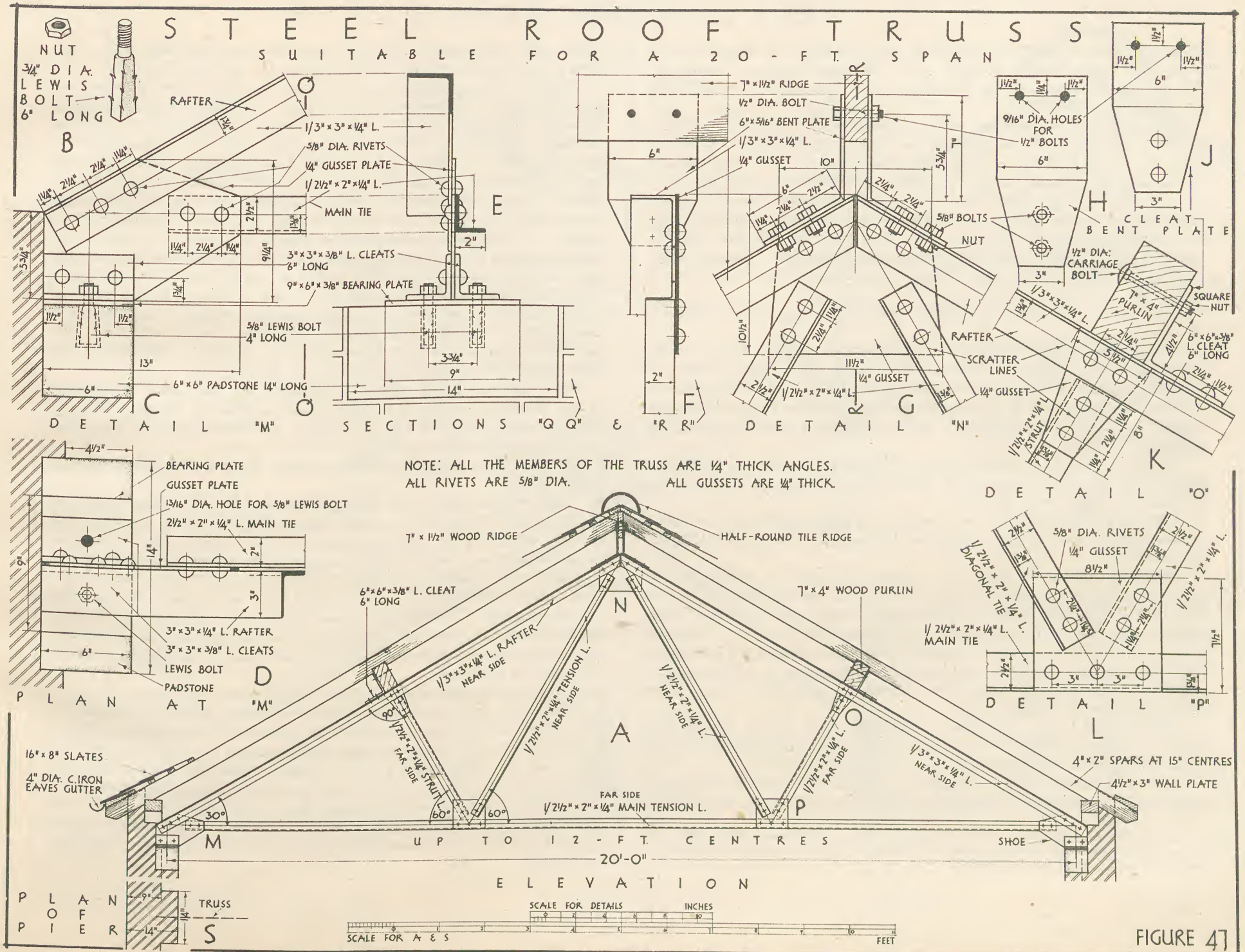

NUT
3/4" DIA. LEWIS BOLT 6" LONG
B
RAFTER
1/3" x 3" x 1/4" L.
5/8" DIA. RIVETS
1/4" GUSSET PLATE
1/2 1/2" x 2" x 1/4" L.
MAIN TIE
E
3" x 3" x 3/8" L. CLEATS 6" LONG
9" x 6" x 3/8" BEARING PLATE
5/8" LEWIS BOLT 4" LONG
13"
6"
6" x 6" PADSTONE 14" LONG
C
DETAIL "M"
SECTIONS "Q Q" & "R R"
7" x 1 1/2" RIDGE
1/2" DIA. BOLT
6" x 5/16" BENT PLATE
1/3" x 3" x 1/4" L.
1/4" GUSSET
10"
F
5/8" BOLTS
NUT
1/4" GUSSET
1 1/2" x 2" x 1/4" L.
G
DETAIL "N"
9/16" DIA. HOLES FOR 1/2" BOLTS
H
CLEAT BENT PLATE
J
1/2" DIA. CARRIAGE BOLT
SQUARE NUT
7" x 4" PURLIN
1/3" x 3" x 1/4" L.
RAFTER
SCRATTER LINES
6" x 6" x 3/8" L. CLEAT 6" LONG
1 1/2" x 2" x 1/4" L. STRUT
K
DETAIL "O"
BEARING PLATE
GUSSET PLATE
13/16" DIA. HOLE FOR 5/8" LEWIS BOLT
2 1/2" x 2" x 1/4" L. MAIN TIE
3" x 3" x 1/4" L. RAFTER
3" x 3" x 3/8" L. CLEATS
LEWIS BOLT
PADSTONE
D
PLAN AT "M"
NOTE: ALL THE MEMBERS OF THE TRUSS ARE 1/4" THICK ANGLES.
ALL RIVETS ARE 5/8" DIA. ALL GUSSETS ARE 1/4" THICK.
7" x 1 1/2" WOOD RIDGE
HALF-ROUND TILE RIDGE
6" x 6" x 3/8" L. CLEAT 6" LONG
7" x 4" WOOD PURLIN
1/3" x 3" x 1/4" L. RAFTER NEAR SIDE
1/2 1/2" x 2" x 1/4" TENSION L. NEAR SIDE
1/2 1/2" x 2" x 1/4" L. NEAR SIDE
A
1/2 1/2" x 2" x 1/4" STRUT L. FAR SIDE
FAR SIDE 1/2 1/2" x 2" x 1/4" MAIN TENSION L.
1/2 1/2" x 2" x 1/4" L. FAR SIDE
1/3" x 3" x 1/4" L. NEAR SIDE
16" x 8" SLATES
4" DIA. C.IRON EAVES GUTTER
4" x 2" SPARS AT 15" CENTRES
4 1/2" x 3" WALL PLATE
30°
60°
60°
90°
M
UP TO 12-FT. CENTRES
SHOE
20'-0"
ELEVATION
5/8" DIA. RIVETS
1/4" GUSSET
8 1/2"
1/2 1/2" x 2" x 1/4" L. DIAGONAL TIE
1/2 1/2" x 2" x 1/4" L. MAIN TIE
L
DETAIL "P"
PLAN OF PIER
TRUSS
S
SCALE FOR DETAILS INCHES
SCALE FOR A & S FEET

FIGURE 47

bolted or riveted to the rafters, the former being preferred. A detail of one of these plates before bending is shown at H. *Care must be taken in setting out that the bolts or rivets connecting these plates to the rafters do not foul the rivets fixing the latter to the gusset.*

The purlins are of wood, and each is bolted to a cleat riveted or bolted to the rafter (see K). If riveted, the cleats are fixed at the works (or on the site *before* the truss is erected). A detail of the cleat is shown at J. Joints between purlins must occur at the trusses, and for such connections the cleats are 12-in. long to enable two bolts being fixed at the end of each purlin (see Q, Fig. 50). The bolts now commonly used for fixing these wood members are called *carriage bolts*, *coach bolts* or *timber bolts*. As shown at K, a carriage bolt has a flat cup head and a square *neck* (portion of the shank next to the head). Washers are not required.[1] Square nuts are used. Alternative purlins are shown at N, S, T and U, Fig. 50.

The detail at L shows the connection between the main and diagonal ties and the strut.

All the rivets are $\frac{5}{8}$-in. diameter. The pitch of the rivets is figured on the drawings. The "$1\frac{1}{4}$-$2\frac{1}{4}$-in." pitch shown is common for this size of rivet. It will also be noted that the sizes of the gussets are figured. A structural engineer's working drawing shows all of these dimensions. Many of them have been omitted in the following drawings in order to prevent a mass of figures from obscuring the details.

Truss suitable for a 30-ft. Span (see Fig. 48).—An outline of the truss is shown at A, the rafters being equally divided by two purlins on each side, and the main tie is also equally divided.

Like the previous example, each member is a single angle, and to obtain a suitable balance some members are fixed at the near side of the gussets and others at the far side.

Details of the shoe are given at C, D and E. The main tie extends for the full width of the base plate and secured to it by a countersunk rivet (see M, Fig. 77, Vol. I) in order to give a level bearing. A short cleat is provided at the opposite side of the gusset and countersunk riveted to the base plate. As shown at D, two $\frac{13}{16}$-in. diameter holes are formed in the plate to receive the lewis bolts. Unlike that shown at C, Fig. 47, the gusset does not project below the main tie, and this arrangement is therefore more suitable if a plastered ceiling without cornices is to be provided.

The details at F and G are those at the heads of the struts. The method adopted of ensuring that the rivets are at least the minimum distance from the edges of the gussets, referred to on p. 121, is indicated (see also B).

The connections at the apex are shown at H, and those between the gusset, main tie, struts and diagonal tie are shown at K. The section at J shows a strut on each side of the gusset. The size of these struts and the diagonal tie is that of the smallest angles used in roof construction, *i.e.*, 2-in. by 2-in. by $\frac{1}{4}$-in.

The purlins in this example are of steel (see F and G). These are sometimes preferred to the timber purlins shown in Fig. 47. It will be noted that the purlins are fixed to the rafters by means of bolts. Rivets are never used for fixing these continuous members, as riveting is not practicable after the trusses have been fixed in position. It should also be observed that the centre line principle has been complied with and that the nut comes centrally between the pair of rivets below. Wood plates, called *fillers*, must be bolted at 2-ft. 6-in. to 3-ft. intervals to the purlins as shown to provide fixings for the spars. They are in short lengths. An alternative arrangement is shown at B, where the purlins are reversed and the fillers are placed against their backs. Whilst this is as sound as the type shown at F and G, the fillers are not so readily fixed. The wood plates, not being in continuous lengths, can be laid on the purlins if fixed as shown at F until required to be bolted, but such a temporary support is not available if the purlins are arranged as shown at B. The latter detail is adopted if soffit boarding is required and which is nailed direct to the fillers. The form of end joint between steel purlins is described on p. 128.

The detail at the ridge shows an alternative but more costly arrangement to that detailed at G, Fig. 47; this is usually adopted for the direct fixing of asbestos-cement sheets (see Fig. 47, Vol. III). The steel members are continuous and the spars are nailed to the fillers.

The usual type of tapered gutter is detailed at C and the external walls are $13\frac{1}{2}$-in. thick.

Truss suitable for 30 to 40-ft. Spans (see Fig. 49).—The setting out of the truss is shown in the outline elevation at G. All the members, with exception of the rafters, are of 2-in. by 2-in. by $\frac{1}{4}$-in. angles. The rafters, main tie and main struts, consist of double angles with the gussets in between (see B).

The shoe is detailed at C, D and E. Both angles of the main tie are countersunk riveted to the base plate. Two slotted holes are formed in the base plate for the lewis bolts. These enlarged holes, as previously explained, are to facilitate fixing and not, as sometimes imagined, to allow for expansion and contraction due to temperature changes which, in such a small roof, are negligible. A sketch of the shoe is given at B.

The wood ridge connection is similar to that shown at G, Fig. 47.

The double members (rafters, main tie and main struts) are stiffened and held at the correct distance apart by the provision at intermediate points of *washer packings* placed between them and connected by bolts or *tacking rivets* (see A and H). The thickness of the washers equals that of the gussets, *i.e.*, $\frac{5}{16}$-in. According to the B.S.S. No. 449, the pitch of these tacking rivets should not exceed 3-ft. 6-in. when the members are in tension and 2-ft. 6-in. for compression members. In very large roofs the thickness of these washers may be as much as 2-in. to provide adequate space between the backs of the members for painting.

[1] A hole, of diameter equal to that of the bolt, is bored in the wood purlin. The bolt is inserted and the square-necked portion driven home. The latter prevents rotation of the bolt when the nut is being tightened.

STEEL ROOF TRUSS

SUITABLE FOR A 30-FT. SPAN

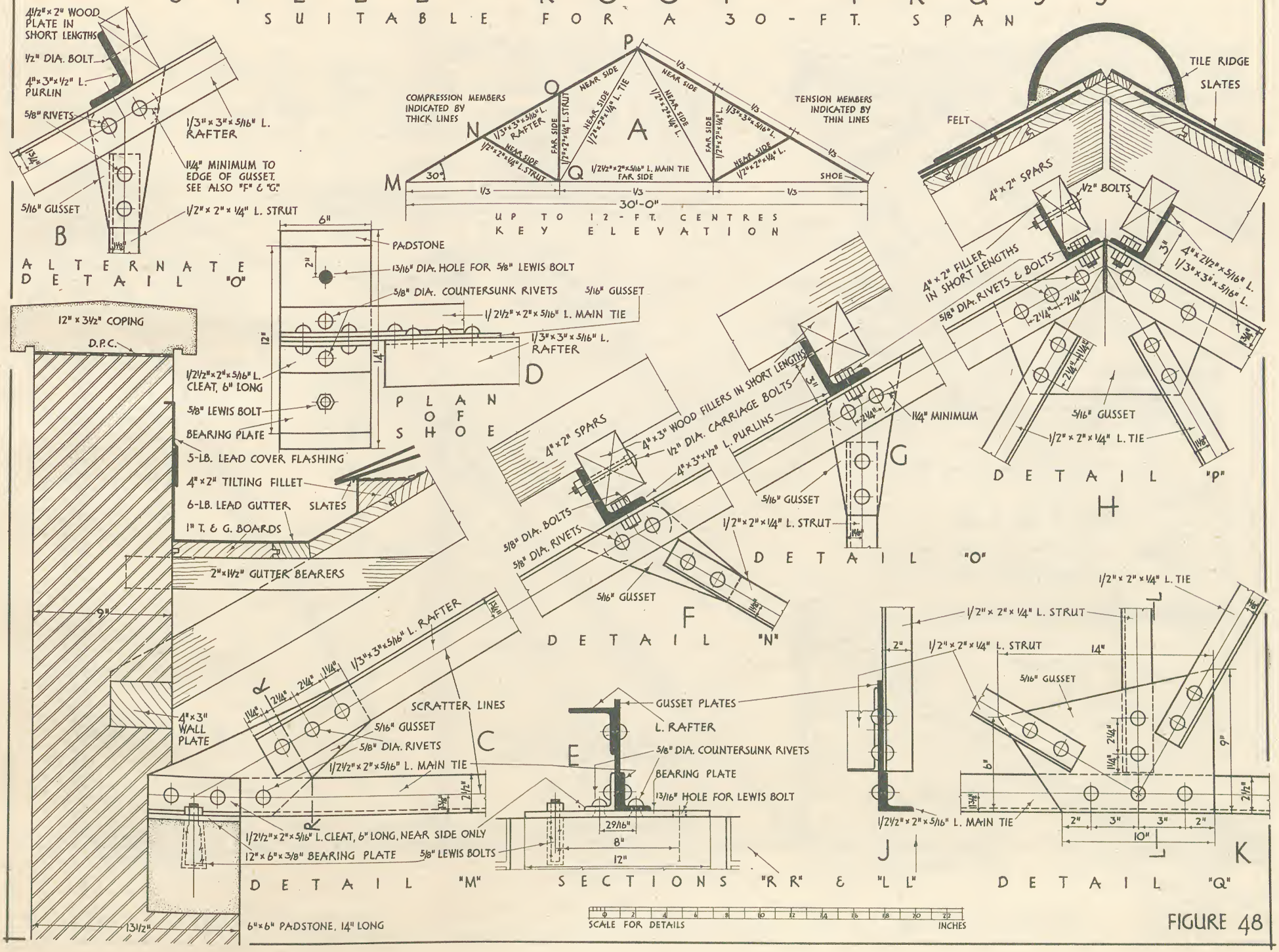
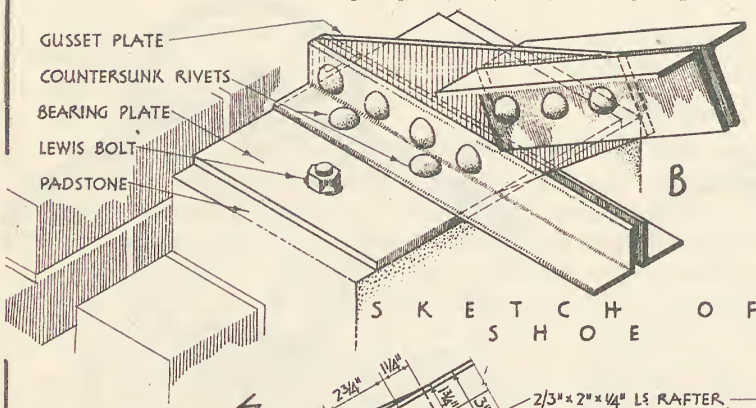


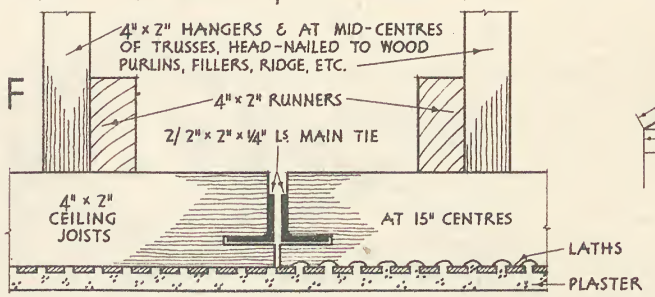
FIGURE 48

STEEL ROOF TRUSS

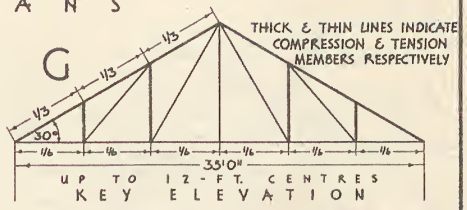
SUITABLE FOR 30-40-FT. SPANS



SKETCH OF SHOE


F
4" x 2" HANGERS & AT MID-CENTRES OF TRUSSES, HEAD-NAILED TO WOOD PURLINS, FILLERS, RIDGE, ETC.
4" x 2" RUNNERS
2/ 2" x 2" x 1/4" Ls MAIN TIE
4" x 2" CEILING JOISTS
AT 15" CENTRES
LATHS
PLASTER

SECTION "L"



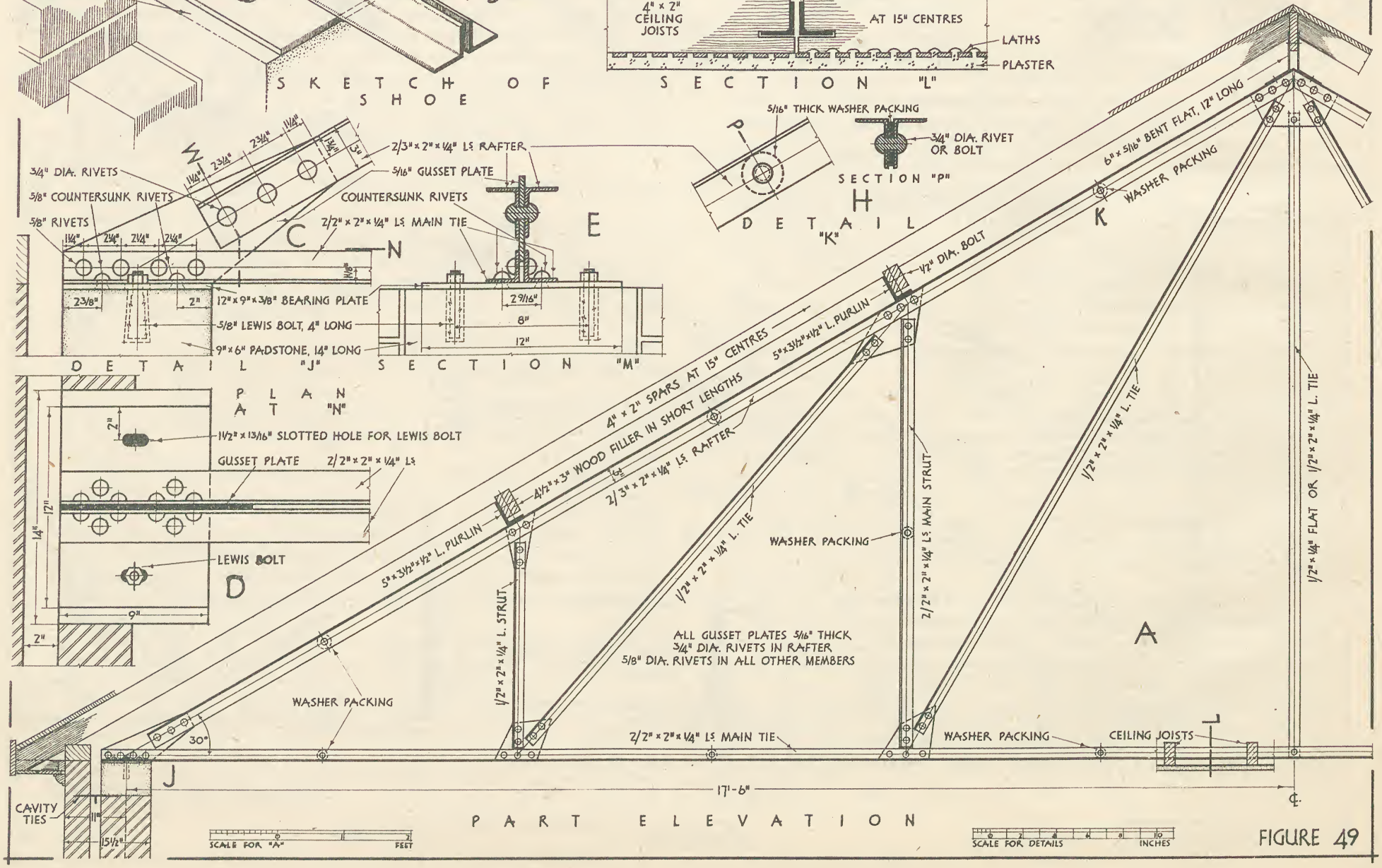
KEY ELEVATION

DETAIL "J" SECTION "M"

SECTION "P"

DETAIL "K"

PLAN AT "N"


6" x 5/16" BENT FLAT, 12" LONG
WASHER PACKING
K
1/2" DIA. BOLT
4" x 2" SPARS AT 15" CENTRES
5" x 3 1/2" x 1/2" L. PURLIN
4 1/2" x 3" WOOD FILLER IN SHORT LENGTHS
2/ 3" x 2" x 1/4" Ls RAFTER
1/2" x 2" x 1/4" L. TIE
WASHER PACKING
2/ 2" x 2" x 1/4" Ls MAIN STRUT
1/2" x 2" x 1/4" L. TIE
1/2" x 2" x 1/4" L. STRUT
ALL GUSSET PLATES 5/16" THICK
3/4" DIA. RIVETS IN RAFTER
5/8" DIA. RIVETS IN ALL OTHER MEMBERS
A
WASHER PACKING
30°
2/ 2" x 2" x 1/4" Ls MAIN TIE
WASHER PACKING
CEILING JOISTS
J
17'-6"
CAVITY TIES
11"
15 1/2"

PART ELEVATION

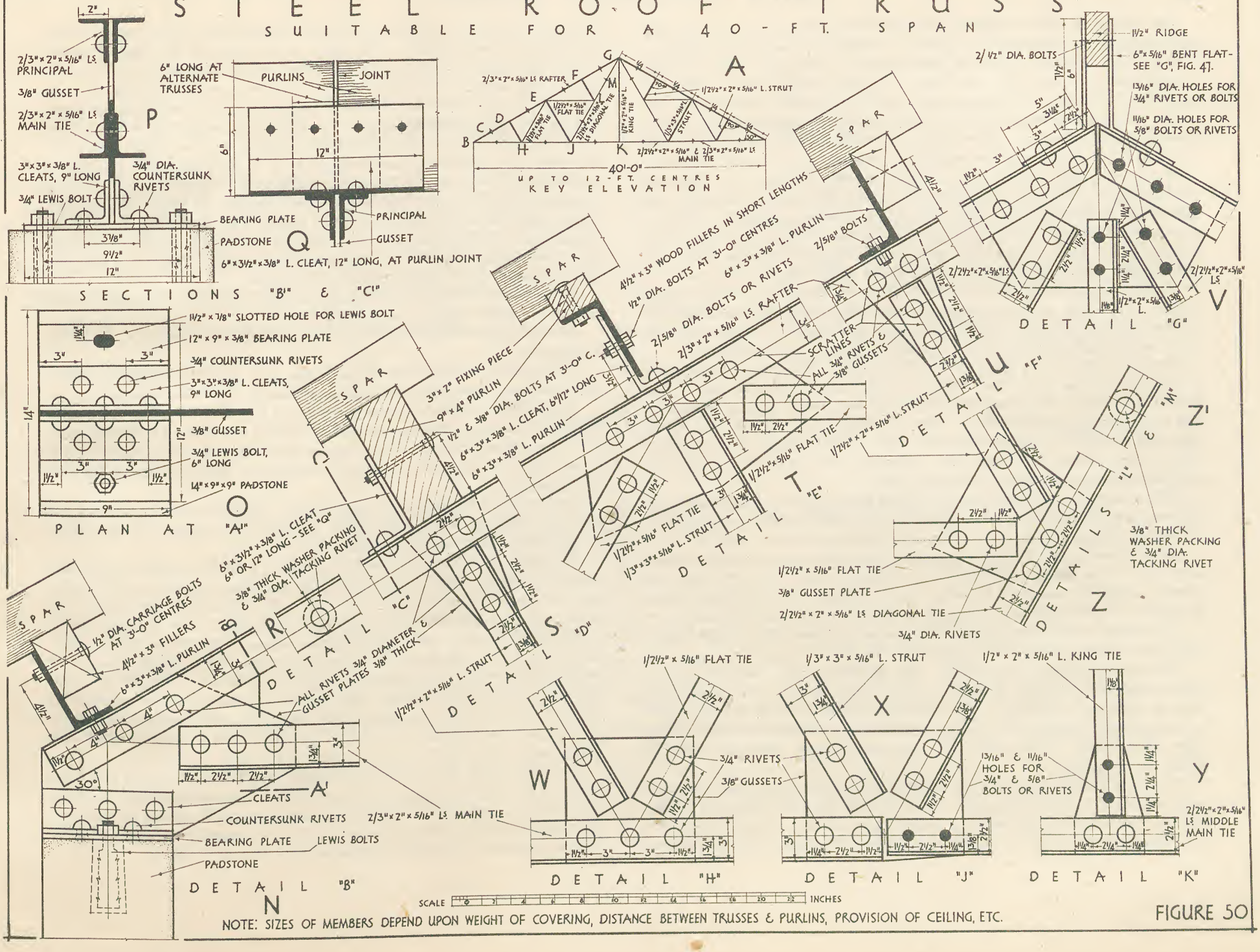
SCALE FOR "A" FEET

SCALE FOR DETAILS INCHES

FIGURE 49

STEEL ROOF TRUSSES

SUITABLE FOR A 40-FT. SPAN


2/3" x 2" x 5/16" L.S. PRINCIPAL
3/8" GUSSET
2/3" x 2" x 5/16" L.S. MAIN TIE
3" x 3" x 3/8" L. CLEATS, 9" LONG
3/4" DIA. COUNTERSUNK RIVETS
3/4" LEWIS BOLT
BEARING PLATE
PADSTONE
3 1/8"
9 1/2"
12"
P
6" LONG AT ALTERNATE TRUSSES
PURLINS
JOINT
6"
12"
PRINCIPAL
GUSSET
6" x 3 1/2" x 3/8" L. CLEAT, 12" LONG, AT PURLIN JOINT
Q
SECTIONS "B" & "C"
A
2/3" x 2" x 5/16" L.S. RAFTER
1/2 1/2" x 2" x 5/16" L. STRUT
1/2 1/2" x 5/16" FLAT TIE
1/2" x 2" x 5/16" L. KING TIE
2/2 1/2" x 2" x 5/16" L.S. DIAGONAL TIE
1/3" x 3" x 5/16" L. STRUT
2/2 1/2" x 2" x 5/16" & 2/3" x 2" x 5/16" L.S. MAIN TIE
40'-0"
UP TO 12-FT. CENTRES
KEY ELEVATION
1 1/2" RIDGE
2/ 1/2" DIA. BOLTS
6" x 5/16" BENT FLAT - SEE "G", FIG. 47.
13/16" DIA. HOLES FOR 3/4" RIVETS OR BOLTS
11/16" DIA. HOLES FOR 5/8" BOLTS OR RIVETS
2/2 1/2" x 2" x 5/16" L.S.
1/2" x 2" x 5/16" L.
V
DETAIL "G"
1 1/2" x 7/8" SLOTTED HOLE FOR LEWIS BOLT
12" x 9" x 3/8" BEARING PLATE
3/4" COUNTERSUNK RIVETS
3" x 3" x 3/8" L. CLEATS, 9" LONG
3/8" GUSSET
3/4" LEWIS BOLT, 6" LONG
14" x 9" x 9" PADSTONE
14"
12"
9"
O
PLAN AT "A"
SPAR
4 1/2" x 3" WOOD FILLERS IN SHORT LENGTHS
1/2" DIA. BOLTS AT 3'-0" CENTRES
6" x 3" x 3/8" L. PURLIN
2 5/8" DIA. BOLTS OR RIVETS
2 5/8" BOLTS
2/3" x 2" x 5/16" L.S. RAFTER
SCRATTER LINES
ALL 3/4" RIVETS & 3/8" GUSSETS
3" x 2" FIXING PIECE
9" x 4" PURLIN
1/2" & 3/8" DIA. BOLTS AT 3'-0" C.
6" x 3" x 3/8" L. CLEAT, 6 1/2" LONG
6" x 3" x 3/8" L. PURLIN
C
DETAIL "C"
T
DETAIL "E"
U
DETAIL "F"
1/2 1/2" x 2" x 5/16" L. STRUT
1/2 1/2" x 5/16" FLAT TIE
Z'
& "M"
"L"
3/8" THICK WASHER PACKING & 3/4" DIA. TACKING RIVET
1/2 1/2" x 5/16" FLAT TIE
3/8" GUSSET PLATE
2/2 1/2" x 2" x 5/16" L.S. DIAGONAL TIE
3/4" DIA. RIVETS
Z
DETAILS
6" x 3 1/2" x 3/8" L. CLEAT 6" OR 12" LONG - SEE "Q"
3/8" THICK WASHER PACKING & 3/4" DIA. TACKING RIVET
R
DETAIL "C"
1/2" DIA. CARRIAGE BOLTS AT 3'-0" CENTRES
4 1/2" x 3" FILLERS
6" x 3" x 3/8" L. PURLIN
ALL RIVETS 3/4" DIAMETER & GUSSET PLATES 3/8" THICK
1/2 1/2" x 2" x 5/16" L. STRUT
S
DETAIL "D"
30°
CLEATS
A'
COUNTERSUNK RIVETS
2/3" x 2" x 5/16" L.S. MAIN TIE
BEARING PLATE
LEWIS BOLTS
PADSTONE
N
DETAIL "B"
1/2 1/2" x 5/16" FLAT TIE
1/3" x 3" x 5/16" L. STRUT
1/2" x 2" x 5/16" L. KING TIE
3/4" RIVETS
3/8" GUSSETS
W
DETAIL "H"
X
DETAIL "J"
13/16" & 11/16" HOLES FOR 3/4" & 5/8" BOLTS OR RIVETS
Y
DETAIL "K"
2/2 1/2" x 2" x 5/16" L.S. MIDDLE MAIN TIE
SCALE
INCHES

NOTE: SIZES OF MEMBERS DEPEND UPON WEIGHT OF COVERING, DISTANCE BETWEEN TRUSSES & PURLINS, PROVISION OF CEILING, ETC.

FIGURE 50

The vertical tie, called a *king tie* and connected at the apex and to the main tie, is required as an intermediate support, if, as shown at F, a plastered ceiling is to be provided. Otherwise it can be dispensed with. It is shown to be a flat bar. As explained on p. 121, flats are likely to become damaged in the course of transport and erection of the truss, and a small angle is often preferred for this reason. There is very little stress in this member (0·5-tons only) and only one bolt is shown at each connection. If two-bolted or riveted connections are insisted upon (see p. 121) the details would be modified to those shown at V and Y, Fig. 50.

A common method of fixing the wood ceiling joists is shown at F. The joists are fitted tightly between the vertical legs of the angles of the main ties, the ends being notched over the horizontal legs as shown. These are nailed to runners provided near each truss and at mid-centres, and the runners are spiked to hangers, the heads of which are nailed to purlins (if of wood) or fillers and to the ridge. Runners and hangers are detailed in Fig. 38, Vol. I.

The remaining details will be understood from the description of the previous trusses. The rivets are $\frac{3}{4}$-in. diameter for the rafter angles and $\frac{5}{8}$-in. diameter for the remaining members. All the gussets are $\frac{5}{16}$-in. thick. The external walls are of cavity construction with 14-in. by $4\frac{1}{2}$-in. piers at truss intervals.

TRUSS SUITABLE FOR A 40-FT SPAN (see Fig. 50).—The outline elevation at A shows the setting out. Each rafter is divided into four equal parts. The struts are normal to the rafters and the foot of each main diagonal tie scratter line meets the intersection between those of the 3-in. by 3-in. by $\frac{5}{16}$-in. main strut and main tie. When arriving at the sizes of the members it was assumed that the roof covering was slates, that a plastered ceiling had to be supported, and that the distance between trusses was 12-ft.

This is known as a *Fink*, *French* or *Belgium* truss and is of good design, each half consisting of a symmetrical triangulated frame. The king tie is only necessary if a ceiling is required and serves as an additional support for the main tie.

As stated on p. 122, the gauge or scratter lines and not the centre lines have been drawn when setting out these details. This is in conformity with the usual practice adopted by structural engineers when preparing working details showing the position of the rivets, etc. The spacing of the rivets is fully dimensioned.

The rafters, main tie and diagonal ties, consist of double angles placed back to back and between which the $\frac{3}{8}$-in. gussets are fixed.

The shoe is detailed at N, O and P. The padstone is 9-in. thick (or equal to three courses of brickwork), as it has to accommodate two $\frac{3}{4}$-in. lewis bolts which are 6-in. long (see B, Fig. 47). Two cleats are riveted to the gusset and these are countersunk riveted to the bearing plate in which slotted holes for the fixing bolts are provided. The section at P shows the double rafter and main tie riveted to the gusset.

Trusses of this size cannot be conveniently transported as complete structures from the works to the building site. Each truss is therefore fabricated in two halves at the works and conveyed in parts to the building. Thus the left half detailed in Fig. 50 would be riveted together with the gusset plate at the apex connected as shown and holed in order that the right half may be readily bolted or riveted to it subsequently. The gusset at the bottom of the diagonal tie will be fixed and holed similarly, and the detached *middle* main tie will have a holed gusset plate riveted at its centre to receive the lower end of the king tie. On arrival on the site each truss is quickly assembled by (*a*) connecting the upper ends of the rafter and diagonal tie of the right half to the apex gusset, (*b*) bolting or riveting (according to the type of fixing designed for) the middle main tie to the gusset at X and to the corresponding plate on the right half truss, and (*c*) connecting the king rod to the apex and middle main tie gussets. If site riveting is resorted to, all of these members are fixed together by means of temporary service bolts before the final operation is carried out; if they are to be bolted connections, which are common, the nuts are not finally spannered until all the bolts have been inserted. It will be observed that the diameter of the holes is $\frac{1}{16}$-in. larger than that of the bolt or rivet shanks.

As the stress in the main tie decreases towards the centre, the middle portion consists of smaller angles, as shown at X.

The king tie is sometimes omitted if the roof is to be open, *i.e.*, no ceiling is required.

The detail at Z is somewhat similar to that at W, and, with exception of those of the purlins, a description of it and the remaining details is unnecessary.

Four different types of purlins are shown at N, S, T and U. That connecting the feet of the trusses (N) is similar to that detailed at F and G, Fig. 48, described on p. 124. Members such as this may be provided at the shoes of each of the trusses shown in Figs. 47, 48 and 49 if preferred to fixing the feet of the spars to wall plates.

An alternative to the above is shown at U. Here the purlin is reversed and the short plates are bolted at the back. For the reason stated on p. 124, this is not so convenient for fixing the fillers.

The large wood purlin shown at S is fixed in a similar manner to that illustrated at K, Fig. 47, but the cleat leg fixed to the rafter is shorter, as the required two bolts or rivets are provided when one is fixed to each of the angles of the rafter. The purlins should be sufficiently long to span across two bays (24-ft.) to allow their ends to come over alternate trusses. The cleats will be 12-in. long at the purlin ends (see Q) and 6-in. long at the intermediate trusses. These purlin joints should be staggered to ensure that all the joints do not come over the same pairs of trusses. The type of end joint used for steel purlins, like those in Figs. 48 and 49, and N and U, Fig. 50, usually consists of a 3-in. by 3-in. by $\frac{3}{8}$-in. angle cleat, twice bolted to the back of the rafter, to which each purlin end is twice bolted.

The steel purlin at T is bolted to an angle cleat bolted or riveted to the two angles of the rafter. A 3-in. by 2-in. wood plate is carriage-bolted or coach-screwed (see p. 126, Vol. I) to it at 3-ft. intervals to provide a fixing for the spars. This type of purlin, without the wood plate, is commonly employed for fixing asbestos-cement or corrugated iron sheets (see K, M and N, Fig. 47, Vol. III).

HOMEWORK PROGRAMME

THE following schedule follows closely that provided on pp. 160 and 161, Vol. I; a suggested guide to reading has been added. For the reasons there stated, it is not possible to compile a programme of homework which will suit every class of student, especially for such a comprehensive subject as Building Construction. A lecturer will, of course, select subject-matter for homework which will be of most value to his students, having regard to their capacity and specific needs. The following subjects have therefore been selected to meet what are considered to be average requirements.

Although the proposed guide for reading covers the whole book, it will be appreciated that much of the description, especially that related to materials, is for reference purposes, and students will therefore concentrate upon those sections which have special reference to their own particular syllabuses.

As stated on p. 160, Vol. I, it is assumed that the drawing sheets will be of half-imperial size and that the maximum number of sheets which may be produced varies from twenty-four to twenty-eight, according to the length of session.

The homework programme for the second year of the course is continued on p. 135, Vol. III, and deals with carpentry, joinery and roof coverings.

Sheet Number. Number of Lectures per Session.				Subject of Drawing.	Reading (Pages).
24	25	26	27		
1	1	1	1	CAVITY WALLS.—Draw quarter full-size details B, D (including proper damp proof course), A (lower portion) and J, Fig. 13.	1-12, 36-44.
2	2	2	2	REINFORCED BRICKWORK.—Sketch details showing the application to walls B, pillars and lintels, Fig. 16.	12-19, 44-51.
3	3	3	3	ARCHES.—Draw, to $\frac{3}{4}$-in. scale, A, B, C and J (half), Fig. 19, and P. 14 (half), Fig. 24.	19-27, 51-52.
4	4	4	4	DAMP PROOFING.—(*a*) Draw, to 1-in. scale, details C and E, Fig. 20.	28-36, 52-58.
				STEPPED FOUNDATIONS.—(*b*) Draw, to a scale of 4-ft. to 1-in., elevation of a 14-in. wall, 40-ft. long, with stepped foundations, assuming the ground to have an irregular fall of 6-ft. (see Fig. 22).	59-60.
5	5	5	5	FIREPLACES, ETC.—(*a*) Draw, to $\frac{3}{8}$-in. scale, A, B, C, N, O and P, Fig. 25; (*b*) draw 1-in. details V, W and X, Fig. 25.	60-64, 64-70.
6	6	6	6	DRAINAGE.—Sketch: (*a*) A, J, Q, U and V, Fig. 28; (*b*) C, D, F, G and M, Fig. 29.	71-78.
7	7	7	7	DRAINAGE.—(*a*) Draw, to a scale of 8-ft. to 1-in., block plan of a detached house and show the drainage scheme to meet the requirements of your local authority. There are three rain water pipes, and the sanitary fittings include a sink, two lavatory basins, bath and two water closets. The sewer, boundaries, etc., must be shown. Refer to Fig. 30. (*b*) Draw 1-in. plan and cross-section of an inspection chamber. Refer to Figs. 30 and 31.	78-84.
8	8	8	8	MASONRY.—Draw: (*a*) $\frac{3}{4}$-in. plan, vertical section and elevation of entrance A, Fig. 38, assuming a 12-in. cavity wall with $5\frac{1}{2}$-in. stone outer leaf; (*b*) half full-size detail at A *or* B, Fig. 39.	85-97, 105-113.
			9	MASONRY.—Draw: (*a*) $\frac{1}{2}$-in. elevation C, section B and plan of entrance, Fig. 38; (*b*) full-size detail of head of architrave at S *or* T, Fig. 39.	107.
9	9	9	10	MASONRY.—Draw: (*a*) $\frac{3}{4}$-in. elevation J, section L and elevation M of windows, Fig. 40; (*b*) full-size details at D and E, Fig. 41.	97-105, 113-120.
10	10	10	11	STEEL TRUSS.—Draw: (*a*) $\frac{3}{4}$-in. elevation A, Fig. 47; (*b*) quarter full-size details at C, G, K and L, Fig. 47.	121-124.
11	11	11	12	STEEL TRUSS.—Draw: (*a*) to a scale of 4-ft. to 1-in., elevation A, Fig. 48; (*b*) quarter full-size details at C, F, H and K, Fig. 48.	124-128.
12	12	12	13	STEEL TRUSS.—Draw: (*a*) to a scale of 8-ft. to 1-in., elevation A, Fig. 50; (*b*) quarter full-size details at N, R, S, T, U, V, W, X, Y and Z, Fig. 50.	128.

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